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(54) **FULL DUPLEX RADIO TRANSCEIVER WITH REMOTE RADAR DETECTION**

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None

See application file for complete search history.

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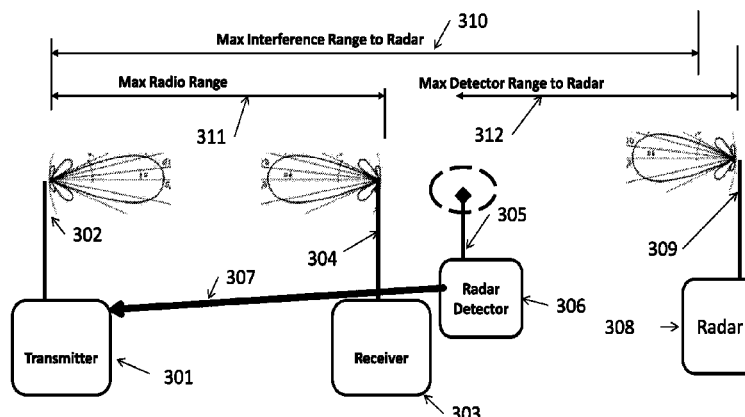
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ABSTRACT

A radar detector is used with a radio link, the radio link characterized by high duty factor operation of a radio transmitter. The radar detector is located a sufficient distance from the radio transmitter that the radar detector is not overwhelmed by the radio transmission signal in that channel and can detect sufficiently low level radar signals to ascertain potential radio interference at the radar from said radio transmitter. The results of the radar detection are communicated to the transmitter in a way that impacts the transmitter's use of the sensed channel. This communication can occur reactively when a radar detection is achieved (the absence of which indicates no radar has been detected) and/or can be a periodic or event-driven indication that the channel is available for operation (the information expiring if the result is not refreshed).

51 Claims, 9 Drawing Sheets



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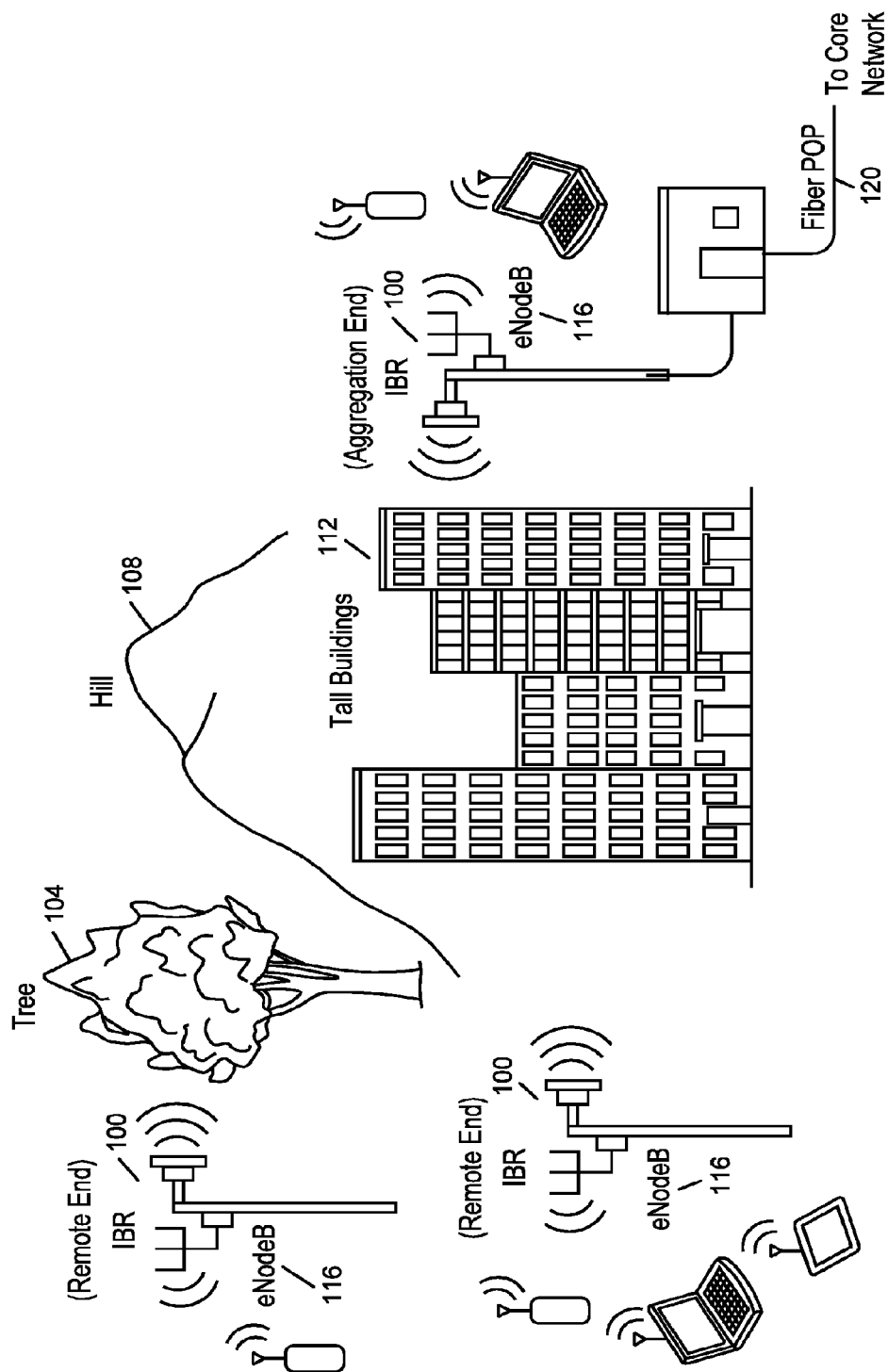


FIG. 1

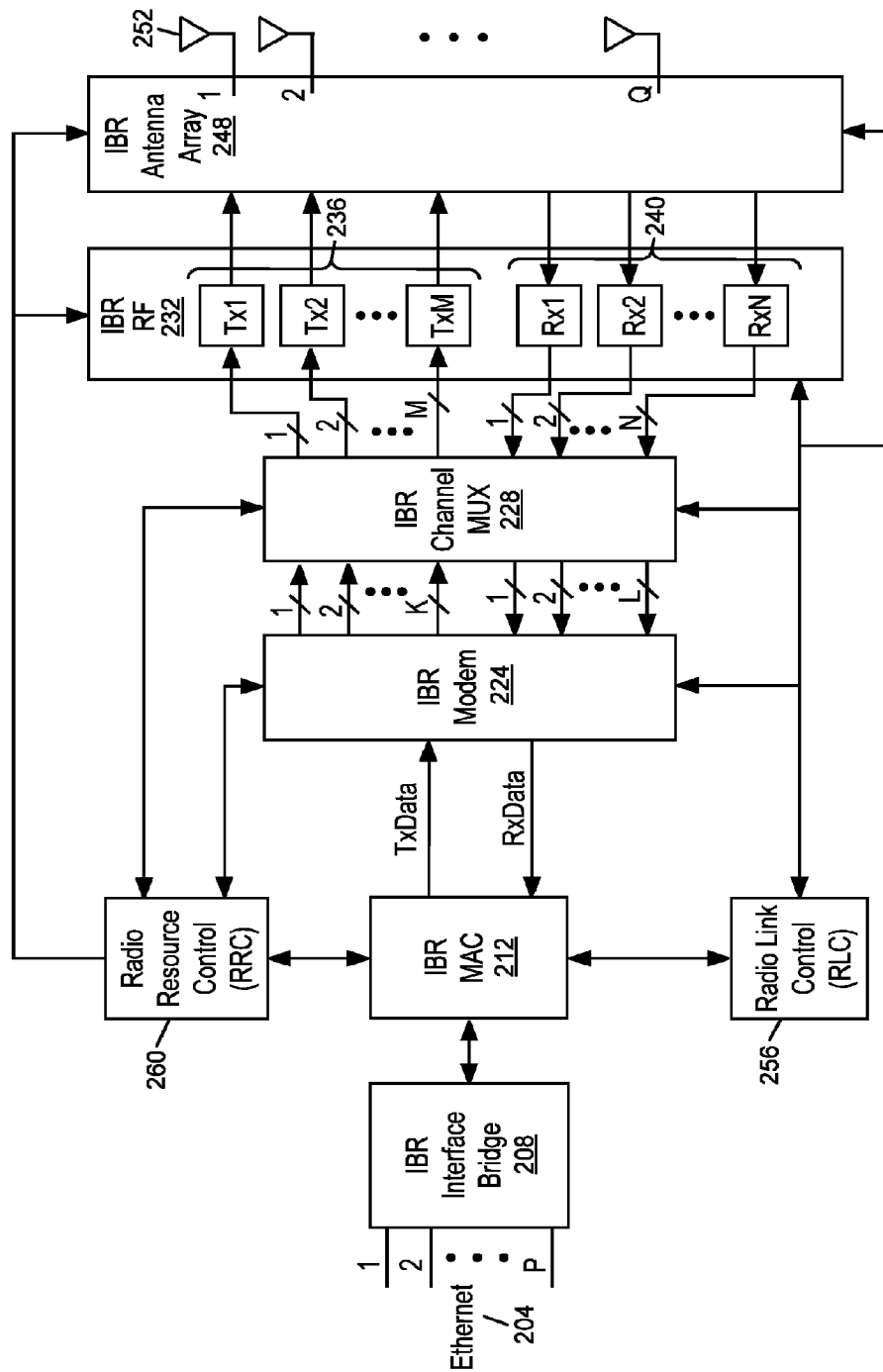


FIG. 2

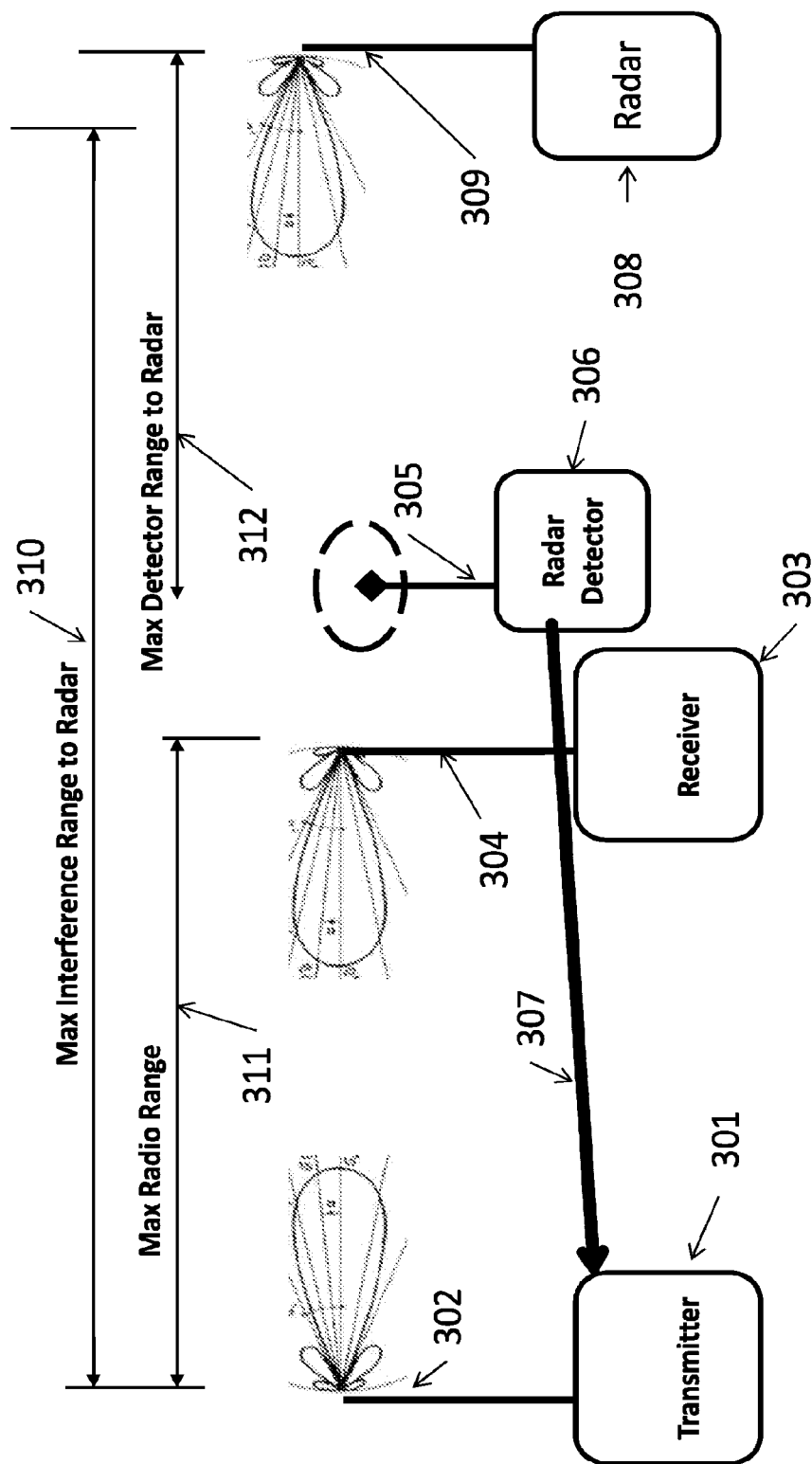


FIG. 3

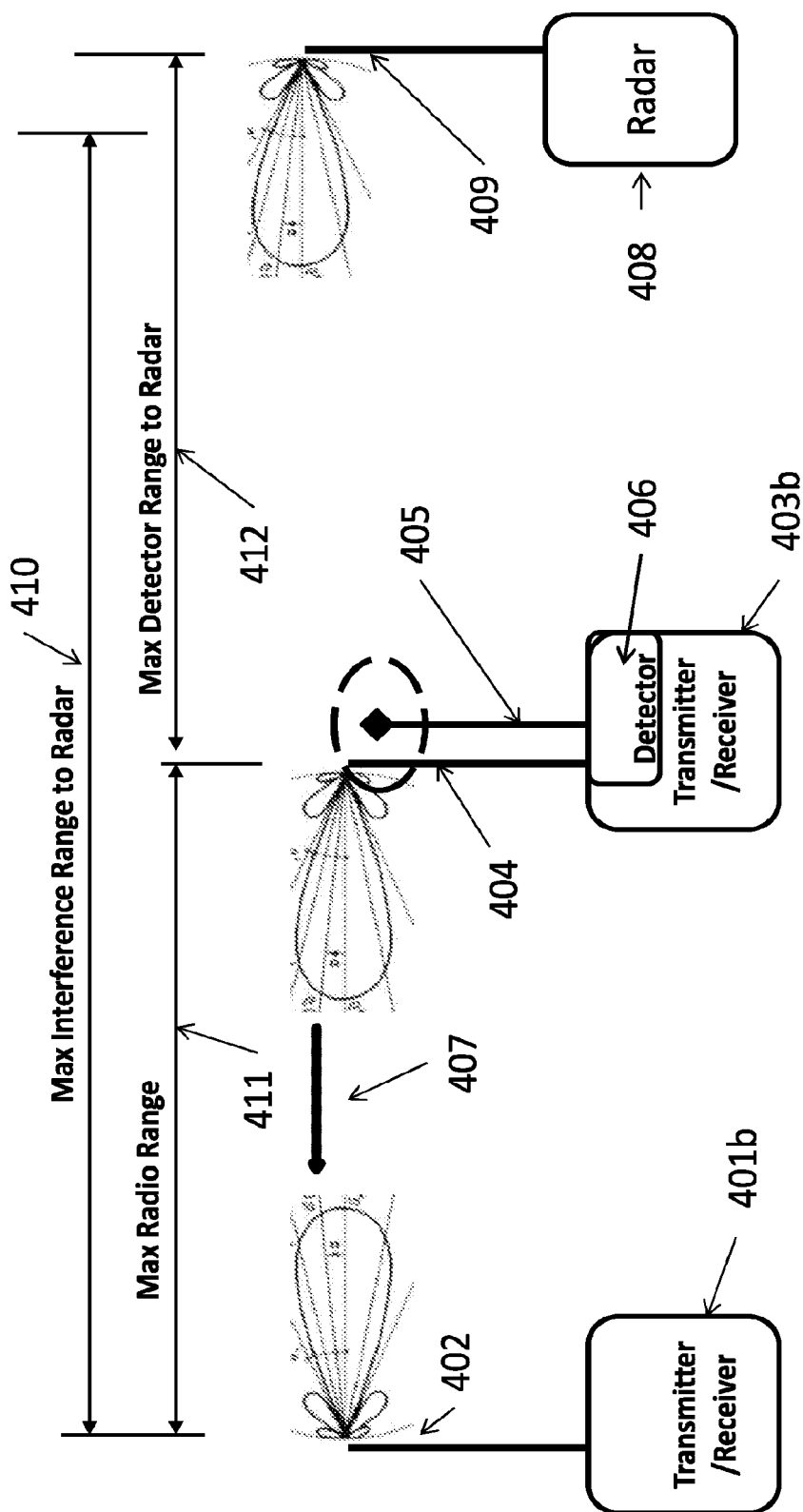


FIG. 4

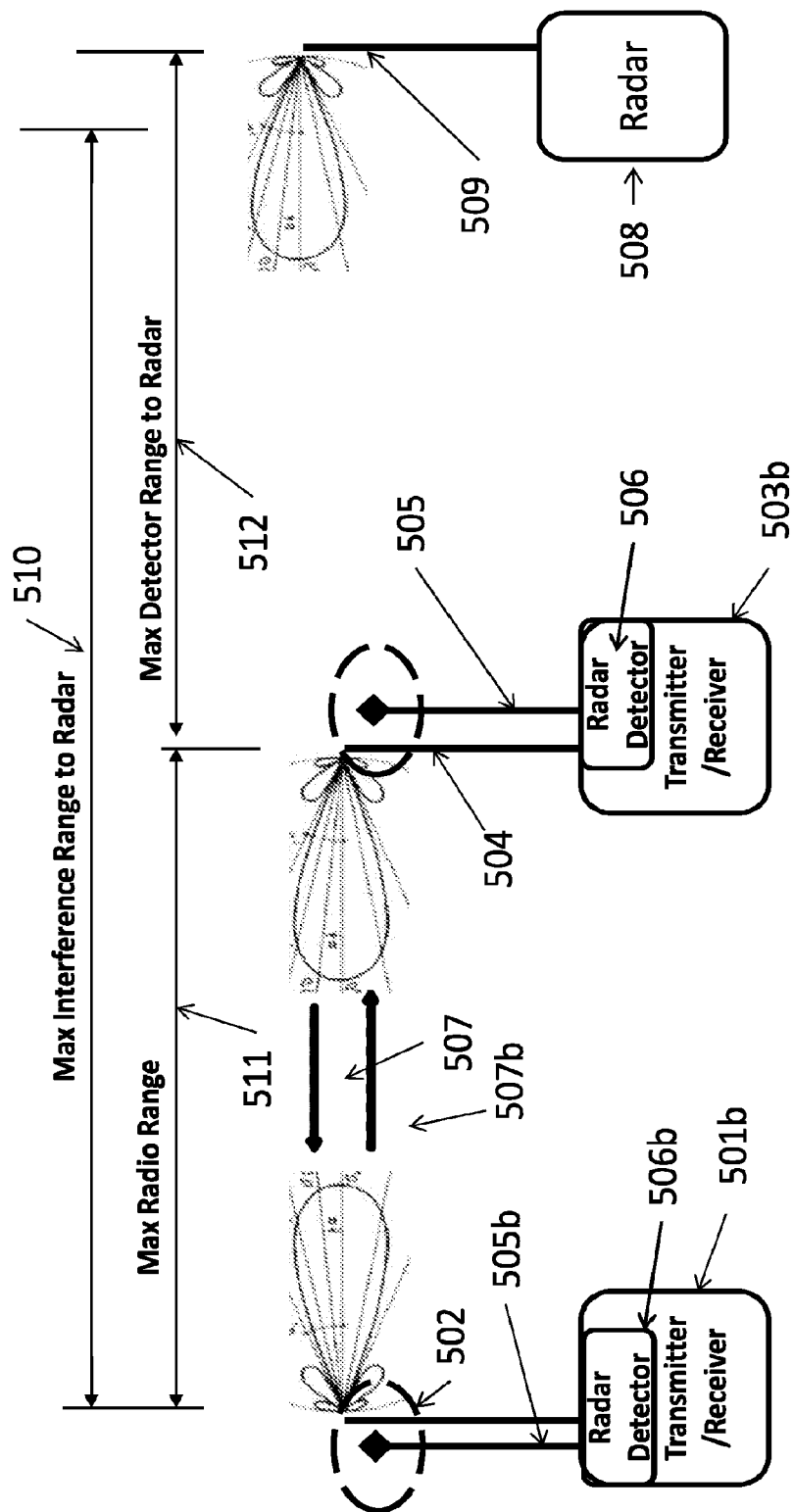


FIG. 5

FIG. 6A

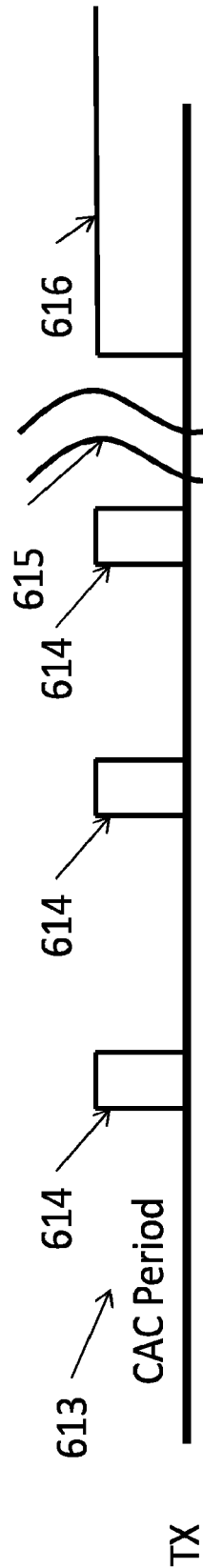
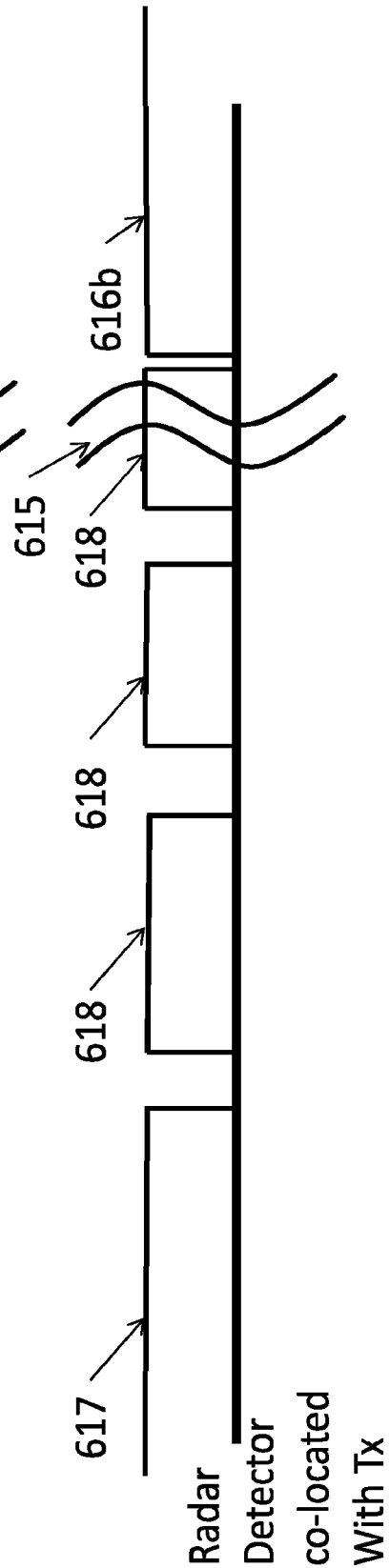


FIG. 6B



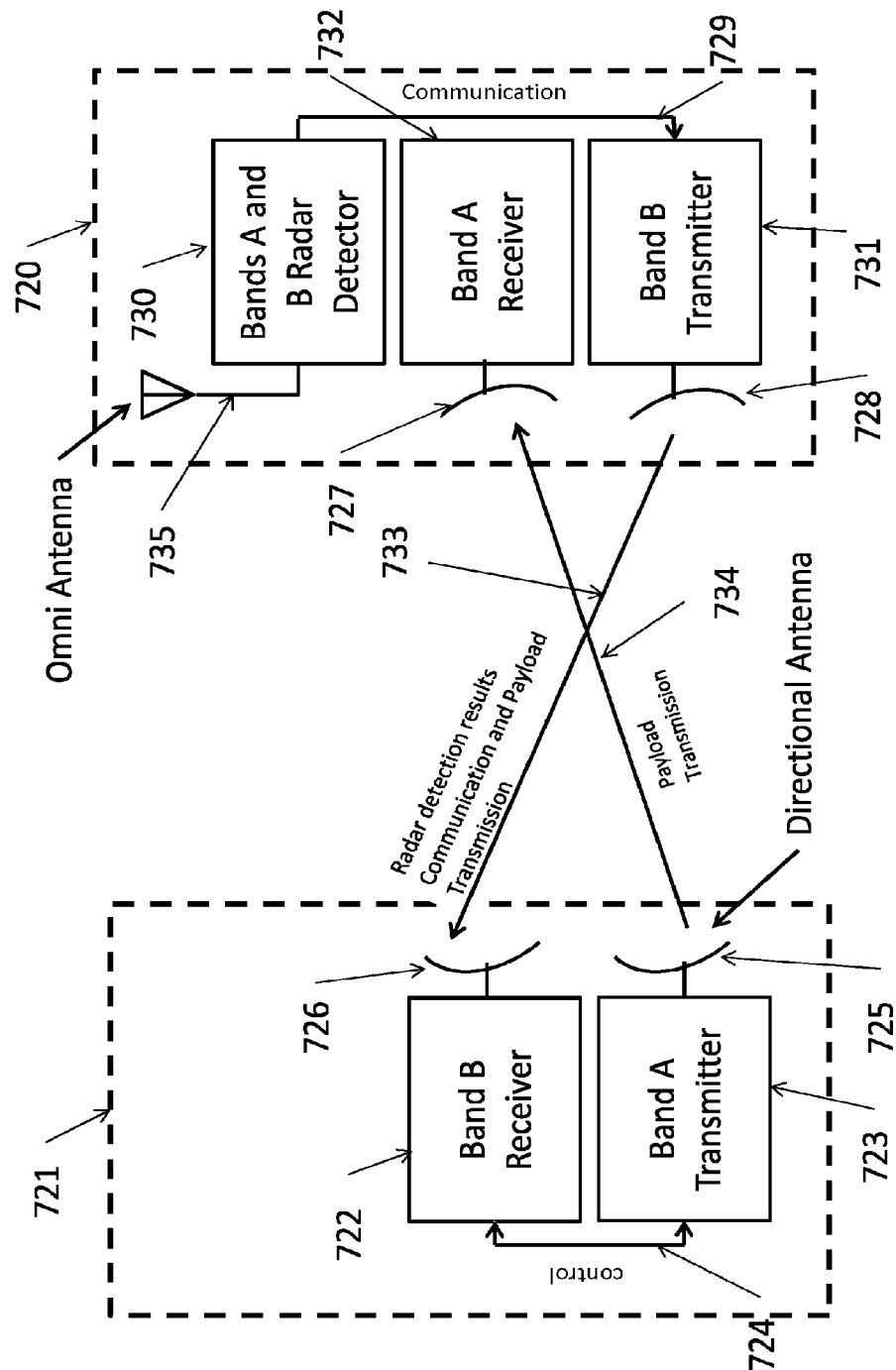


FIG. 7

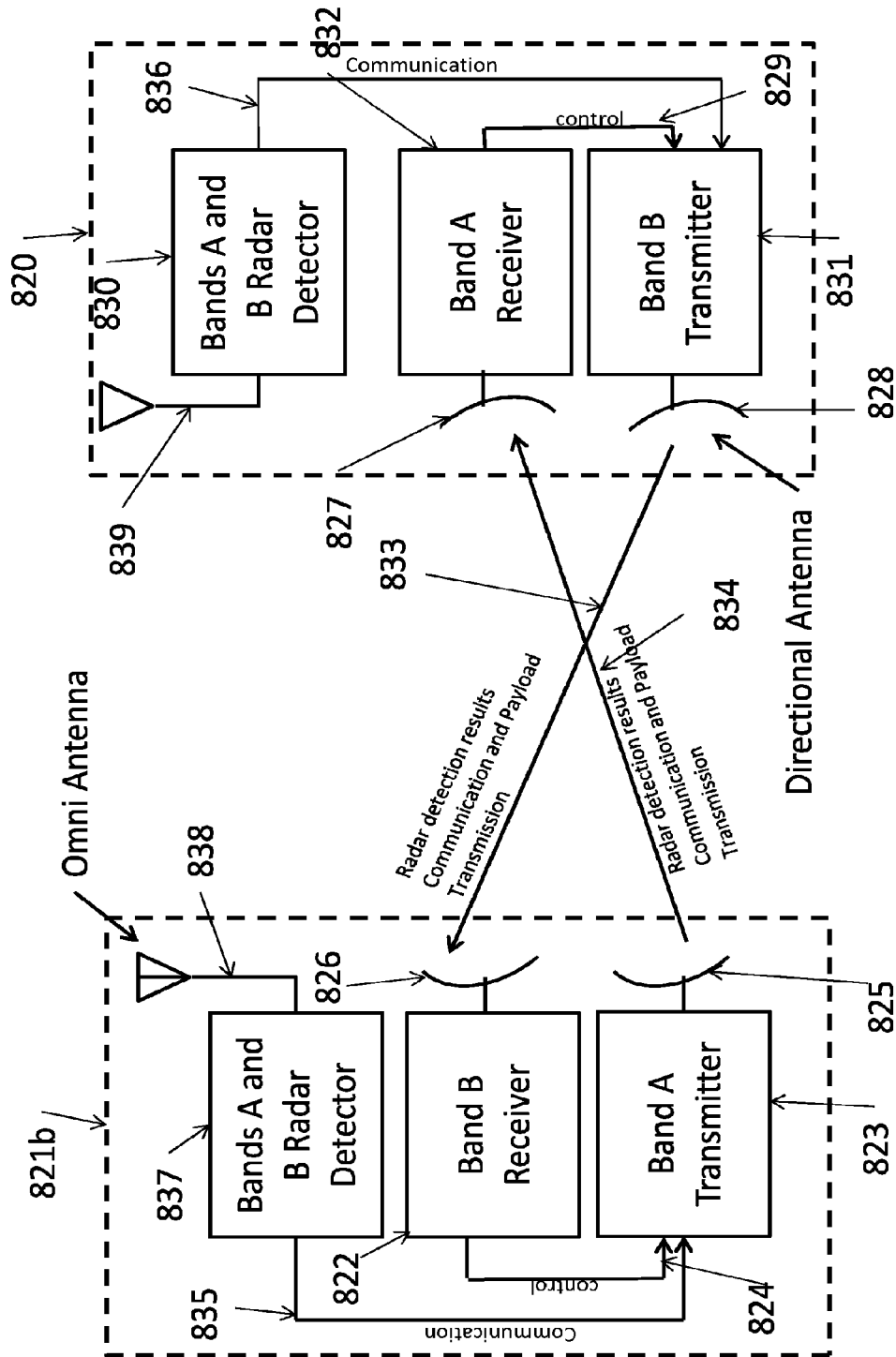
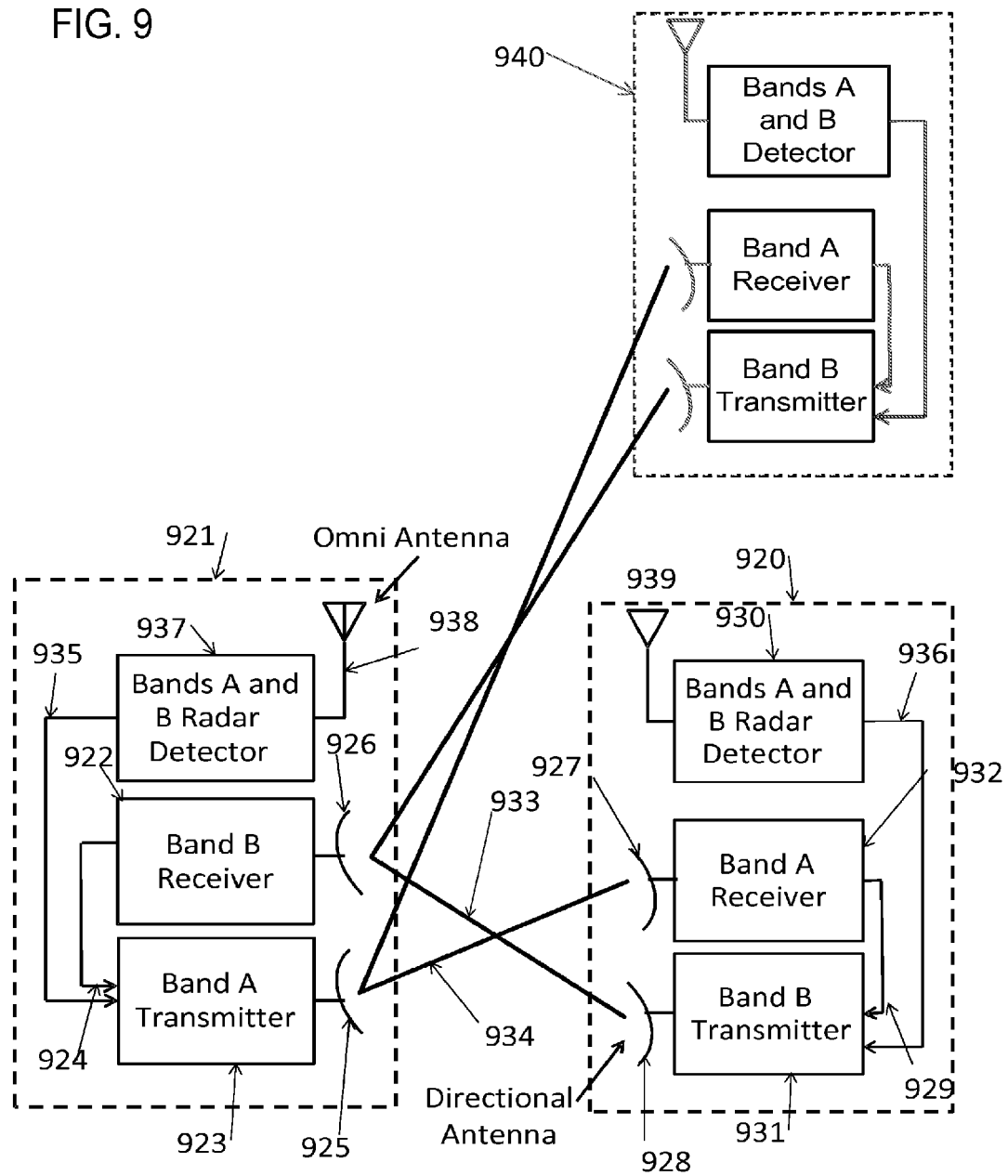


FIG. 8

FIG. 9



FULL DUPLEX RADIO TRANSCEIVER WITH REMOTE RADAR DETECTION

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation application of U.S. patent application Ser. No. 14/151,190, filed on Jan. 9, 2014, which is a continuation-in-part application of U.S. patent application Ser. No. 13/645,472, filed on Oct. 4, 2012, now U.S. Pat. No. 8,811,365, which is a continuation of U.S. patent application Ser. No. 13/371,366, filed on Feb. 10, 2012, now U.S. Pat. No. 8,311,023, which is a continuation of U.S. patent application Ser. No. 13/212,036, filed on Aug. 17, 2011, now U.S. Pat. No. 8,238,318, the disclosures of which are hereby incorporated herein by reference in their entirety. Also, U.S. patent application Ser. No. 14/151,190, filed on Jan. 9, 2014, also claims priority to U.S. Provisional Patent Application Ser. No. 61/857,661, filed Jul. 23, 2013, entitled “Intelligent Backhaul Radio with Improved Radar Detection Capability”, the entirety of which is hereby incorporated by reference.

The present application is also related to U.S. patent application Ser. No. 13/536,927, filed Jun. 28, 2012 and now U.S. Pat. No. 8,467,363, U.S. patent application Ser. No. 13/609,156, filed Sep. 10, 2012 and now U.S. Pat. No. 8,422,540, U.S. patent application Ser. No. 13/767,796, filed Feb. 14, 2013 and now U.S. Pat. No. 8,638,839, U.S. patent application Ser. No. 13/898,429, filed May 20, 2013 and now U.S. Pat. No. 8,824,442, and U.S. Provisional Patent Application Ser. No. 61/910,194, filed Nov. 29, 2013, the disclosures of which are hereby incorporated herein by reference in their entirety.

BACKGROUND

1. Field

The present disclosure relates generally to data networking and in particular to radar detection with a radio transceiver for connecting remote edge access networks to core networks.

2. Related Art

Connections to remote edge access networks from core networks are often achieved with wireless radio, wireless infrared, and/or copper wireline technologies. Radio, especially in the form of cellular or wireless local area network (WLAN) technologies, is particularly advantageous for supporting mobility of data networking devices. However, cellular base stations or WLAN access points inevitably become very high data bandwidth demand points that require continuous connectivity to an optical fiber core network. When data aggregation points, such as cellular base station sites, WLAN access points, or other local area network (LAN) gateways, cannot be directly connected to a core optical fiber network, then an alternative connection, using, for example, wireless radio or copper wireline technologies, must be used. Such connections are commonly referred to as “backhaul.” The array of network backhaul and other high throughput radio applications include point-to-point, point-to-multipoint, networks of multiple point-to-point and multipoint links, ad hoc, ring, self-organizing and mesh networks. These network architectures, often using directive antennas, are needed to support wireless last mile hops and wireless backhaul applications that are used to bring high throughput services to cellular telephone systems and broadband services to enterprises and the home.

Increasingly, high throughput services to consumers and business are becoming one of the cornerstones of future eco-

nomics vitality. It is very efficient to support these high-demand needs using frame-based transmission links, and particularly so with very high duty factor transmission frequency domain duplexing (FDD). A frame-based system refers to radios with continuous or near-continuous time transmission where time is divided into frames. Each frame carries channel estimation and control information, as well as multiple opportunities to stuff incoming packet-based data onto the frame. When there is no network data available, the frame is transmitted with dummy data blocks. This allows the dropping of incoming data into the data blocks with very low latency and high reliability. The low latency comes from the fact that the link is already running and just needs to substitute the incoming data for the dummy data. The high reliability comes from the fact that the link can be set up and maintained over a period of time that is longer than what would be efficient in a packet radio link. This view of frame-based operation is consistent with the definition of “frame based” in the European ETSI standard EN 301 893.

Radio signals can interfere with radar reception. Because the protection of radar operation is important, regulatory bodies control channel access of radio systems that share the band with radars and set up radar signal level limits for detection of various types of radar signals. In many regulatory regions, a transmitted radar signal that is detected by a radio’s radar detector at -64 dBm is considered too close to the radio system and the radio system must cease transmitting on that channel and move to another channel. A channel is the occupied bandwidth of the data transmission stream over the RF link. But a channel may comprise more than one noncontiguous part where each part can have a different center frequency and occupied bandwidth. The channel frequency of each part is its center frequency.

Although effective for high performance communications, FDD frame-based radio operation makes detection of radar signals using conventional methods impossible. In effect, frame-based transmission is similar to circuit switched operation of the older telephone circuit switching technology. In an FDD link, frame based transmitters can operate at up to 100% transmit duty factor because the responses for each channel arrive in the other channel—a single transceiver can operate with up to 100% transmit duty factor in one channel and up to 100% receive duty factor in another channel, while the transceiver on the other end of the communication link does the opposite on the channels. Various implementations may use less than 100% duty factor to, for example, sense the channel to satisfy a channel sharing regulation or system wide self-interference requirements. But, in each case, the duty factor is significantly higher than a packet radio system and can approach 100% in many cases. Thus, with typical FDD radios, the transmitters on both ends of an FDD link usually transmit together coincident in time for at least some fraction of every frame. When the transmit duty factor is high, this means that radar detection for one or both of the transmit directions is preferably performed within a fraction of every frame that includes this fraction where both ends of an FDD link transmit together coincident in time.

In bands that require radar detection, there is typically a sequence of stages that a transmitter goes through before and at the beginning of operation. In the first stage, prior to operation, the transmitter determines whether the channel is clear of radar transmissions. The regulatory agencies call this stage Channel Availability Check (CAC). In CAC, the radar detector informs the transmitter that a channel cannot be used if certain types of radar are detected. If such radars are detected, the channel is typically off limits for 30 minutes, at which time another CAC must be performed. The next stage is link

operation. In the link operation stage, the receiver detects and acquires the transmission and a round trip connection is made (for full duplex). Often, the receiver and transmitter negotiate an operating frequency. During this period of time, which may be part of a radio channel “bootstrap” sequence, radar monitoring may continue. Typically, there is a 200 ms regulatory requirement for a transmitter to stop transmitting after a radar pulse sequence occurs on a channel. If the bootstrap sequence is a significant duration on the scale of 200 ms, then, under most regulatory requirements, radar monitoring is still needed. After the bootstrap sequence, normal run-mode operation can occur. During this time, in-service monitoring for the radar occurs. The in-service monitoring requires the detection of the presence of certain types of radar on an operating channel and closing the transmission within 200 ms (i.e. the required close time) of the end of the radar pulse train that is used to certify this operation in testing. It should be noted that over the course of a radio’s operating time, it may re-enter the bootstrap mode and the normal run-mode operation multiple times, particularly if the synchronization between the radios is disrupted, or even as a normal maintenance operation.

One problem with existing networks is that when the transmitter is transmitting, the high signal level swamps out the receive signals for typical receivers that are located in close proximity to the transmitter, thereby limiting the ability for a radar detector co-located with the transmitter to detect a radar signal.

Packet radio systems, such as WiFi, handle this by testing their radar detection operation while transmitting at low duty factor, typically much less than 40% transmission period. These packet radio systems detect the radar with a co-located detector at the transmitter while the transmitter is not sending and the radio is available to receive or is receiving. The channel monitoring applies to the next time the transmitter operates. If a WiFi system operates with a transmit traffic load such that it uses a high duty factor, it can miss radar detections.

US20070264935 to Behzad Mohebbi, assigned to Nextivity, describes a bi-direction FDD link for use in the 5 GHz USA UNII-2 band, which requires radar detection. Because the Mohebbi disclosure is bi-directional in nature, it first transmits FDD in one direction on frequency channel 1, while receiving on frequency channel 2, then switches so that the same radio that was transmitting on channel 1 now transmits FDD on channel 2 and receives on frequency channel 1. Although the radar detector for the local transmitter is co-located with the transmitter, the detection is performed on the transmitter channel during the half cycle period that the transceiver is receiving on that channel for the forthcoming transmission. In this way, the Mohebbi disclosure is closely related to WiFi, which performs radar detection when in receive mode for forthcoming transmissions; Mohebbi differs in that it is not performing radar detection for the transmitter that is operating on the other end of the link. Mohebbi is more accurately described as a pair of TDD links, each on one frequency, which have anti-phase transmit/receive cycles. In other words, there is a TDD transmission between radios on channel 1 and another on channel 2, but at each transceiver, it transmits on channel 1 while receiving on channel 2 and vice versa. In Mohebbi, each transceiver transmits a first portion to the other on a frequency 1, while receiving from the other on frequency 2, and radar detecting on a frequency 2; and, each transceiver transmits a second portion to the other on the frequency 2, while receiving from the other on the frequency 1, and radar detecting on frequency 1. Therefore, each transceiver in Mohebbi performs radar detection on both fre-

quency 1 and frequency 2 during the receive period for that frequency to enable the transmission on that frequency on the opposite TDD cycle, similar to the way a WiFi packet radio radar detector operates. It cannot perform radar detection on the transmit channel while the transmitter is transmitting. The Mohebbi system is also inferior in radio performance because it requires a clear channel available in both directions for two frequencies, which is very difficult to achieve from a frequency planning point of view. Additionally, the UNII-2 band is a commonly used unlicensed band that has no controls on interference. The best performance occurs in channels that show the lowest interference levels; interference is a receiver phenomenon. The level of interference measured at the transmitter is uncorrelated to that measured at the receiver simply because there is different propagation from an arbitrarily placed interference source to each side. It is only the interference level at the receiver and not the transmitter that matters because that is what causes reduced signal to interference levels. If a transceiver must receive at two frequencies to maintain a link, it must find two channels that are relatively free of interference to operate, making it much harder to create a good link; in a probabilistic interference setting, this requirement, at a minimum, squares the difficulty of operation. Moreover, in the system of Mohebbi these two channels must be clear at both transceivers on either end of the link and for backhaul radios separated by considerable distances this also squares the difficulty of operation because the interference environments at each end of the link are likely quite different. Also, since the receiving period is the time when the radar detection for the transmitter must be performed in Mohebbi, the transmit and receive channels for one of the pair of “first and second portions” must be the same. That is why it is effectively a pair of TDD channels.

In a WiFi application, the transmissions are packetized and the transmitters generally operate at a low duty factor. In fact, when the transmitters are tested for regulatory compliance for radar detection, they operate at less than a 40% duty factor. Packet radio systems are able to detect radars with the radar detector co-located with the transmitter because they detect the radar signals during the typically greater-than-60% of the time the transmitter is not transmitting.

Thus, the frame-based FDD system has particular challenges for performing radar detection under the various regulatory requirements around the world because, unlike packet-based transmitters such as WiFi radios that can operate at a modest duty factor, the frame-based transmitter is active at high duty factors. There is no opportunity for performing in-service monitoring local to the transmitter under the conventional art because the detection mechanism must listen for signals at -64 dBm while the transmitter is operating on the same channel at, for example, +30 dBm or higher and at nearly 100% duty factor.

By most regulations, a channel which requires radar detection cannot be occupied before completing a 60 second listen period for radars (CAC). If a radio transceiver is forced to vacate its operating channel and it does not have another channel queued up that it has already performed a successful CAC on, it will have to remain off the air for at least 60 seconds. An outage of this length is unacceptable in many applications.

Also, it is often a regulatory requirement that when a radar is detected in a channel, at least 80% of the occupied bandwidth of the channel must be vacated and must remain unused by the detecting system for at least 30 minutes, despite the actual receiver operating bandwidth of the radar. But for wideband devices, as are often found in high-duty-factor links that achieve high throughput, this unduly punishes a

system for spreading its channel power over a wider bandwidth, thus reducing its spectral power density.

SUMMARY

The following summary of the invention is included in order to provide a basic understanding of some aspects and features of the invention. This summary is not an extensive overview of the invention and as such it is not intended to particularly identify key or critical elements of the invention or to delineate the scope of the invention. Its sole purpose is to present some concepts of the invention in a simplified form as a prelude to the more detailed description that is presented below.

Some embodiments of the claimed invention are directed to point-to-point links, a point-to-two-point link, general point-to-multipoint, networks of multiple point-to-point and multipoint links, ad hoc, self-organizing and mesh networks in which a radar detector is co-located with the receiver of the transmission in the channel on which it is detecting. This approach can outperform a radar detector that is co-located at the transmitter.

In an additional exemplary embodiment, a higher degree of directionality for the transmit signal antenna than for the radar detection antenna is used, which biases the detection operation in favor of the radar detector so that the radar will be detected at the receiver at a greater range than it will be interfered with by the radio transmitter. In an additional exemplary embodiment, the radio link uses a directional antenna for the radio link transmitter and an omnidirectional antenna or antenna that is omnidirectional in azimuth is used for the radar detector and it is taught that other combinations work well also.

Embodiments of the invention are applicable to both frequency division duplex (FDD) operation and time division duplex (TDD) operation of the radio link. Performance can be improved with an FDD link using a radar detector co-located with the receiver on the channel on which it is detecting, because the detector can listen for the radar with 100% duty factor. This high-duty factor availability of the radar detector creates a peak-detection capability over time that insures the detector is exposed to the largest radar signal of the time varying channel, mitigating the losses from multipath fading due to channel variations and a rotating radar detection antenna.

According to an aspect of the invention, a wireless communications system is disclosed that includes a first transceiver, wherein the first transceiver includes a first transmitter, a first receiver, and a first radar detector, and wherein the first transmitter transmits on a first transmit channel; a second transceiver, wherein the second transceiver includes a second transmitter and a second receiver, and wherein the second transmitter transmits on a second transmit channel; wherein the first receiver receives from the second transmitter on the second transmit channel and the second receiver receives from the first transmitter on the first transmit channel; wherein the first transmit channel is within a first transmit frequency band and the second transmit channel is within a second transmit frequency band; wherein the first radar detector is configured to detect radars within a first radar detection frequency range that includes at least part of the second transmit frequency band; wherein the first radar detector is configured to detect radars within at least a first time period, the first time period comprising at least a period of time when the first transmitter and the second transmitter both transmit coincident in time; wherein the first radar detector communicates at least a first radar detection result via the first trans-

mitter to the second receiver; and wherein the first radar detection result is an input to a controller associated with the second transmitter.

The first radar detector may be configured to be not transmit-impaired by the second transmitter when the second transmitter transmits, at least in part due to a physical separation of the first radar detector and the second transmitter.

The first radar detector may be configured to be not transmit-impaired by the first transmitter when the first transmitter transmits, at least in part due to a physical separation of the first radar detector and the first transmitter.

The first radar detector may be configured to be not transmit-impaired by the first transmitter when the first transmitter transmits, at least in part due to an the antenna pattern of the first radar detector relative to the antenna pattern of the first transmitter.

The controller associated with the second transmitter may cause the second transmitter to adjust at least one adjustable parameter associated with the second transmit channel.

The at least one adjustable parameter associated with the second transmit channel may be a transmit power of the second transmitter.

The at least one adjustable parameter associated with the second transmit channel may be a center frequency or a channel bandwidth.

The transmit power of the second transmitter after an adjustment may be at a level below that of a regulatory limit for transmit power within a channel for which a radar has been detected.

The first radar detection frequency range may be at least 80% of the bandwidth of the second transmit channel.

The first radar detection frequency range may further include at least 80% of the bandwidth of an alternate channel that is different from the second transmit channel.

The first radar detection result may be communicated within a radar detection message, control frame or status that at least indicates whether or not at least one radar has been detected within the first radar detection frequency range.

The first radar detection result may be communicated within a radar detection message, control frame or status that at least indicates whether or not at least one radar has been detected within the second transmit channel.

The radar detection message, control frame or status may indicate at least one or both of the bandwidth or center frequency of the at least one detected radar within the first radar detection frequency range.

The part of the first time period when at least the first transmitter and the second transmitter both transmit coincident in time may be 100% of the first time period for which the first radar detector is configured to at least detect radars.

The controller associated with the second transmitter may cause an adjustment or a non-adjustment of at least one adjustable parameter associated with the second transmit channel depending on the first radar detection result.

The first transmit frequency band may overlap in frequency with the second transmit frequency band. The first radar detection frequency range may not overlap in frequency with the first transmit frequency band.

The first radar detection frequency range may be identical to or a subset of the second transmit frequency band.

The wireless communications system may further include a second radar detector; wherein the second radar detector is configured to detect radars within at least a second time period, the second time period including at least a period of time when the first transmitter and the second transmitter both

transmit coincident in time; wherein the second radar detector is configured to detect radars within a second radar detection frequency range.

The first time period may overlap in time with the second time period.

The second radar detection frequency range may exclude the second transmit channel.

The second radar detection frequency range may include at least an alternate channel that is different from the second transmit channel.

The second radar detector may be within the first transceiver; wherein the second radar detector communicates at least a second radar detection result via the first transmitter to the second receiver; and wherein the second radar detection result is an input to the controller associated with the second transmitter.

The second radar detection result may be communicated within a radar detection message, control frame or status that at least indicates whether or not at least one radar has been detected within an alternate channel.

The second radar detector may be within the second transceiver; wherein the second radar detector communicates at least a second radar detection result via the second transmitter to the first receiver; and wherein the second radar detection result is an input to a controller associated with the first transmitter.

The second radar detection frequency range may be identical to or a subset of the first transmit frequency band.

The wireless communications system may further include a third radar detector within the second transceiver; wherein the third radar detector is configured to detect radars within at least a third time period, the third time period including at least a period of time when the first transmitter and the second transmitter both transmit coincident in time; wherein the third radar detector is configured to detect radars within a third radar detection frequency range; wherein the third radar detector communicates at least a third radar detection result via the second transmitter to the first receiver; and wherein the third radar detection result is an input to a controller associated with the first transmitter.

The wireless communications system may further include a cancellation circuit within the first transceiver, wherein the cancellation circuit is coupled to at least the first radar detector; and wherein the cancellation circuit adjusts a signal representative of the output of the first transmitter such that the adjusted signal in combination with a received signal for the first radar detector together result in a reduced level of first transmitter signal impairment to the first radar detector.

The wireless communications system may further include a second radio resource controller comprised within the second transceiver, wherein the second radio resource controller comprises the controller associated with the second transmitter; and wherein the second radio resource controller receives at least one additional link quality input as well as the first radar detection result to adjust at least one parameter associated with the second transmit channel.

The wireless communications system may further include a first radio resource controller comprised within the first transceiver, wherein the first radio resource controller comprises the controller associated with the first transmitter; and wherein the first radio resource controller receives at least one additional link quality input as well as the second radar detection result to adjust at least one parameter associated with the first transmit channel.

According to an aspect of the invention, a system is provided that includes a radio transmitter; and a radar detector to detect radar signals, wherein the radar detector is configured

to detect radar on a radar detection listening frequency, the radar detector separated in distance from the radio transmitter such that the signal from the radio transmitter does not prevent the radar detector from detecting radar signals while the radio transmitter is emitting a transmit signal on the radar detection listening frequency, and wherein the radar detector is configured to communicate information to the radio transmitter if a radar is detected.

The radar detector may be a first radar detector and the system may further include a second radar detector to detect radar signals, wherein the second radar detector is configured to detect radar on a radar detection listening frequency, the second radar detector near enough to the radio transmitter such that signal from the radio transmitter prevents the second radar detector from detecting radar signals while the radio transmitter is emitting a transmit signal on the radar detection listening frequency, and wherein the second radar detector is configured to communicate information to the radio transmitter if a radar is detected.

The radio transmitter may operate at a transmit duty factor that is low enough that the second radar detector can detect radar. The second radar detector may perform radar detection listening on a transmit frequency of the radio transmitter prior to the radio transmitter emitting a signal on the radar detection listening frequency. The second radar detector may perform detection listening while the radio transmitter emits a signal on the radar detection listening frequency at a duty factor that is low enough that the second radar detector can detect radar.

The radar detector may perform radar detection listening while the radio transmitter emits a signal on the radar detection listening frequency. The second radar detector may perform radar detection listening while the radio transmitter emits a signal on the radar detection listening frequency at a duty factor that is low enough that the second detector can detect radar, and the first radar detector may perform radar detection listening while the radio transmitter emits a high duty factor signal on the radar detection listening frequency.

The second radar detector may perform radar detection listening on a frequency that is not the radio transmitter transmission frequency.

The radio transmitter may be a first radio transmitter and the system may further include a second radio transmitter that transmits on a different frequency than the first radio transmitter, and the second radar detector may perform radar detection listening on the transmit frequency of the first radio transmitter.

The first radar detector may receive from a less directive receive antenna pattern than the radio transmitter transmit antenna pattern.

According to another aspect of the invention, a system is provided that includes a plurality of transceivers, each of the plurality of transceivers comprising a receiver and a transmitter, and each of the plurality of transceivers having a radar detector co-located with the transmitter, wherein each radar detector operates in a different channel than the transmitter with which it is co-located.

The radar detector may communicate a radar detection status to at least one of the other of the plurality of transceivers.

Each radar detector may listen in a channel of a transmitter that is not the transmitter with which said radar detector is co-located. One radar detector may listen in a channel of a transmitter that is not the transmitter with which said radar detector is co-located and another radar detector may listen in a channel that is not used by any transmitters in the system.

The radio transmission term band refers to a range of frequencies for which operation is available. It may be the

case that the operating channel, or occupied bandwidth of the transmission, entirely occupies the band, but more often, the operating channel occupies part of the band. It is often the case that a number of operating channels can occupy the band simultaneously. Furthermore, there are interference implications for operating channels to simultaneously occupy the band because even though they may be non-overlapping, there is limited filtering available that can prevent an impact that one transmission has on the reception of another if they are near each other. A band usually refers to an entity larger than a single channel, and the channel locations may be pre-designated so as to minimize potential overlap, or they may be arbitrarily placed on a grid that depends on the technology used. A radio may search for the best channel among available channels to determine the best one to use in the operating environment to get the desired performance. A sub-band refers to major splits of the band which get pre-designated for a purpose which is generally technology dependent, such as a sub-band for uplinks and a sub-band for downlinks, where the channels within these sub-bands get selected by the equipment. Sub-bands, if used, are also generally an entity larger than a channel and which comprise one or more channels. Most regulatory agencies identify bands or sub-bands that a specific set of rules apply to. More than one band may be used for equipment. In an exemplary embodiment, to get separation between uplink and downlink channels one band may be used for an uplink and another band used for a downlink. The bands may have different regulatory requirements.

One radar detector may listen in part of a band or sub-band of a transmitter that is not the transmitter with which said radar detector is co-located and another radar detector may listen in another part of the band or sub-band occupied by a transmitter that is not the transmitter with which said radar detector is co-located.

At least one of the radar detectors may listen on a channel that is not occupied by a transmitter of the system for part of the time the at least one of the radar detectors listens.

The bandwidth of a radar detected by the radar detector is determined and only a bandwidth in the system related to the bandwidth of the detected radar is vacated. The related bandwidth in the system may be the same as the bandwidth of the detected radar. The related bandwidth in the system may be one selected from the group consisting of half, double and quadruple the bandwidth of the detected radar.

According to a further aspect of the invention, a system is provided that includes a plurality of transceivers, the plurality of transceivers comprising a first transceiver, the first transceiver comprising a receiver and a transmitter and a first radar detector co-located with the transmitter, wherein the first radar detector first operates in a transmit channel of the transmitter of the first transceiver and then operates in a transmit channel of another of the plurality of transceivers.

A radar detector serves the purpose of detecting the presence of radars that would be interfered with by the transmitter that the radar detector is working for. The radar detector produces a radar detection result. The radar detection result can be polled or can be pushed from the radar detector. One example is status derived from a signal line such as a general purpose I/O line or logic signal that indicates that a radar is present, or is not present, and if it is present, it may indicate some information about the nature of the radar measurement results that it made, such as the radar center frequency, radar bandwidth, or category of radar type. Another example is a message or control frame sent over a communications interface from the radar detector to some other controller entity with the system that comprises fields that describe if a radar is

present, or is not present, and if it is present, it may indicate some information about the nature of the radar measurement results that it made, such as the radar center frequency, radar bandwidth, or category of radar type. This message can be used to make adjustments to at least one adjustable parameter of the transmitter the radar detector is working for such as the transmit channel number (or numbers), the transmit channel center frequency (or frequencies), the transmit channel bandwidth (or bandwidths), and the transmit channel power (or powers). That adjustment may be a result of the message or signal from the radar detector being converted in format and sent to a controller for the transmitter. The controller for the transmitter may also take several forms. If it is a simple controller, then upon seeing the message that the radar detection occurred in the occupied bandwidth of the transmitter, then the transmission in that bandwidth will be stopped. There is generally a regulatory requirement for how long a radio can take before the transmitter is prevented from further transmissions. A more complex form of control would be if a radio resource controller used the radar detector as an input along with another input (or inputs) such as described in U.S. patent application Ser. No. 13/645,472 or U.S. Provisional Patent Application Ser. No. 61/910,194 and incorporated herein to make decisions such as what the next course of action is besides preventing further transmissions in the channel where the radar detection occurred. An exemplary course of action would be to decide the next channel to go to or a different occupied bandwidth to use and to use the remaining allowed time on the air to communicate that information or negotiate the best alternative among the radios involved. The radio resource controller can utilize information about alternatives combined with the radar detection results to help determine the next step.

The first radar detector may be configured to communicate results of a radar detection status to a transmitter of at least one other transceiver of the plurality of transceivers.

The system may further include a second radar detector, the second radar detector configured to listen for radar on the transmit channel of the transmitter of the first transceiver. The second radar detector may communicate results of a radar detection status to control the transmitter of the first transceiver. An aggregation point of the system may use the information from the first radar detector and the second radar detector to determine radar detection results.

The system may further include a third detector, the third detector configured to listen for radar on the transmit channel of the transmitter of the first transceiver. The third radar detector may communicate results of radar detection status to control the transmitter of the first transceiver. An aggregation point of the system may use the information from the second radar detector and the third radar detector to determine radar detection results.

According to another aspect of the invention, a radio transceiver is disclosed that includes a receiver; a transmitter; a radar detector co-located with the transmitter, wherein the radar detector operates in a different channel than the transmitter with which it is co-located.

The radar detector may communicate information about a radar detection to another radio transceiver in communication with the radio transceiver.

The radar detector may listen in a channel of a transmitter that is not the transmitter with which said radar detector is co-located.

The radar detector may listen in a channel of a transmitter that is not the transmitter with which said radar detector is co-located and another radar detector may listen in a channel that is not used by any transmitters in a network.

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The radar detector may listen in part of a band or sub-band of a transmitter which is not the transmitter with which said radar detector is co-located and another radar detector listens in another part of the band or sub-band occupied by a transmitter which is not the transmitter with which said radar detector is co-located.

The radar detector may listen on a channel that is not occupied by the radar transmitter for part of the time the radar detectors listens.

The radio transceiver may be configured to determine a bandwidth of a radar detected by the radar detector and vacate a bandwidth related to the bandwidth of the detected radar.

According to yet another aspect of the invention, a radio transceiver is disclosed that includes a receiver; a transmitter; and a radar detector co-located with the transmitter, wherein the radar detector first operates in a transmit channel of the transmitter and then operates in a transmit channel of another radio transceiver.

The radar detector may be configured to communicate results of a radar detection to a transmitter of another radio transceiver.

A second radar detector in another radio transceiver may listen for radar on a transmit channel of the transmitter.

The second radar detector may communicate results of a radar detection to control the transmitter.

The radar detector may communicate information to an aggregation point, said aggregation point using the information from the radar detector and the second radar detector to determine radar detection results.

A third radar detector co-located with another radio transceiver may listen for radar on the transmit channel of the transmitter.

The transmitter may receive results of radar detection status from the third radar detector.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated into and constitute a part of this specification, illustrate one or more examples of embodiments and, together with the description of example embodiments, serve to explain the principles and implementations of the embodiments.

FIG. 1 is an illustration of intelligent radio transceivers (IBRs) deployed for cellular base station backhaul with obstructed LOS according to one embodiment of the invention.

FIG. 2 is a block diagram of an IBR according to one embodiment of the invention.

FIG. 3 is a schematic diagram showing radar detection according to one embodiment of the invention.

FIG. 4 is a schematic diagram showing radar detection according to another embodiment of the invention.

FIG. 5 is a schematic diagram showing radar detection according to a further embodiment of the invention.

FIG. 6A is a timeline showing a radar detection process according to one embodiment of the invention.

FIG. 6B is a timeline showing a radar detection process according to another embodiment of the invention.

FIG. 7 is a block diagram showing radar detection according to one embodiment of the invention.

FIG. 8 is a block diagram showing radar detection according to another embodiment of the invention.

FIG. 9 is a block diagram showing radar detection according to a further embodiment of the invention.

DETAILED DESCRIPTION

In a radio system that can have multiple radar detectors, such as a point-to-multipoint and other configurations in the

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array of backhaul networks, the radar detectors become a shared network resource. Embodiments of the invention make use of the shared resource by operating these detectors cooperatively, or in a coordinated manner, to perform the radar detection function efficiently and provide expanded capability such as channel look ahead, extended detection bandwidth, and more reliable detectability through location, angle, and antenna diversity.

Embodiments of the invention perform radar detection at the receiver side for the transmitter that occupies the channel at the same time the transmitter is sending. In some embodiments of the invention, the detector relays the results over a separate communications channel. This separate communications channel may be the part of an FDD link that operates in the other direction. The communication may also be indirect. For example, in some embodiments, communications may be attempted on a channel, and by virtue of not receiving a signal, it may be deduced that the channel is blocked due to radar detection. In another example, in some embodiments, a radar detector may transmit messages that a channel is clear on the channel, and, if radar is detected on the channel, the radar detector stops sending the messages from which it can be determined by transmitters that the channel is blocked due to radar detection.

Embodiments of the invention are also directed to operation of a radar detector in a full duplex system that transmits on the same channel at high duty factor so the detection is preferably performed remotely. This high-duty-factor system is able to determine the actual operating bandwidth required to be vacated in order to protect the detected radar.

Additionally, one or more radar detectors can be task-shared or time-shared so the detector or part of the detector can be reused while monitoring a high-duty-factor transmission system. An exemplary requirement for task sharing is to be able to use the same radar detector to perform monitoring of one channel while time-sharing the detector by performing an alternate channel CAC on another channel at a low duty factor. A background CAC may be performed for an alternate channel that can be used immediately in the event of a radar detection. This alternate channel detection is not disrupted by the adjacent or alternate channel operation of the occupied channel which may be operating at high duty factor.

FIG. 1 illustrates deployment of exemplary intelligent backhaul radio transceivers (IBRs) in accordance with an embodiment of the invention. As shown in FIG. 1, the IBRs 100 are deployable at street level with obstructions such as trees 104, hills 108, buildings 112, etc. between them. The IBRs 100 are also deployable in configurations that include point to multipoint (PMP), as shown in FIG. 1, as well as point to point (PTP). In other words, each IBR 100 may communicate with more than one other IBR 100.

For 3G and especially for 4th Generation (4G), cellular network infrastructure is more commonly deployed using “microcells” or “picocells.” In this cellular network infrastructure, compact base stations (eNodeBs) 116 are situated outdoors at street level. When such eNodeBs 116 are unable to connect locally to optical fiber or a copper wireline of sufficient data bandwidth, then a wireless connection to a fiber “point of presence” (POP) requires obstructed LOS capabilities, as described herein.

For example, as shown in FIG. 1, the IBRs 100 include an Aggregation End IBR (AE-IBR) and Remote End IBRs (RE-IBRs). The eNodeB 116 of the AE-IBR is typically connected locally to the core network via a fiber POP 120. The RE-IBRs and their associated eNodeBs 116 are typically not connected to the core network via a wireline connection; instead, the RE-IBRs are wirelessly connected to the core network via the

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AE-IBR. As shown in FIG. 1, the wireless connection between the IBRs include obstructions (i.e., there may be an obstructed LOS connection between the RE-IBRs and the AE-IBR).

FIG. 2 illustrates an exemplary embodiment of the IBR 100 shown in FIG. 1. In FIG. 2, the IBR 100 includes interfaces 104, interface bridge 108, MAC 112, modem 124, channel MUX 128, RF 132, which includes Tx1 . . . TxM 136 and Rx1 . . . RxN 140, antenna array 148 (includes multiple antennas 152), a Radio Link Controller (RLC) 156 and a Radio Resource Controller (RRC) 160. It will be appreciated that the components and elements of the IBRs may vary from that illustrated in FIG. 2. Additional details regarding the intelligent radio transceiver (IBR) are provided in commonly assigned U.S. patent application Ser. No. 13/645,472, U.S. Pat. No. 8,311,023 and U.S. Pat. No. 8,238,318, the disclosures of which are hereby incorporated herein by reference in their entirety.

The Intelligent Backhaul Radio transceiver (IBR) 100 is used in a point-to-point or point-to-multipoint connection that can be used for any radio interface that requires high throughput, including backhaul of cellular sites, connectivity among entities within an enterprise, Internet to enterprise, or Internet to customer premises equipment, campus networks, connectivity among stations in metropolitan area networks, and connection between Local Area Networks and Internet service.

Embodiments of the invention perform detection of radar signal sources that would be interfered by, or interfere with, the IBR. An exemplary embodiment of the required dynamic frequency selection (radar) requirement in regulatory environments, such as the U.S. and Europe that is used for detecting radars by the IBR equipment while operating radio links at a high duty factor, is used to describe embodiments of the invention.

There are significant advantages to effectively performing the radar detection for each transmitter at the receiver side for the array of wireless networked backhaul applications, such as the exemplary point-to-point and point-to-multipoint systems. In fact, for high duty factor FDD point-to-point systems, the radar detection results obtained when at least one radar detector is also co-located at the FDD receivers and when the radar detector has a less directional radar detection antenna than the transmit signal antenna are better for both operation of the radio link and for minimizing any potential interference with the radars due to the instant radio link than when the radar detection is performed only at the transmitter as known in other types of systems.

Because of the range difference, a radar positioned behind the receiver is closer to the detector than to the interfering radar transmitter. Because the radar detector antenna is omnidirectional or less directional than the radio link directional antennas, a radar located to the side of the pair or behind the transmitter is detected at the receiver before it is interfered with by the transmitter. The transmitter signal is reduced in level at the radar due to the directionality of the antenna, while the radar signal arrives full force at the radar detector.

Also, in an FDD radio using a radar detector co-located with the receiver, the detector can listen for the radar for 100% duty factor. This creates a peak-detection capability that insures the detector finds the largest radar signal of the time varying channel, overcoming the loss of multipath fading and a rotating radar detection antenna. For these reasons, embodiments of the invention are advantageous because the detectability of the radar is better both in the sense that actual radars are more reliably detected and in the sense that accidental false detections of non-existent radars are greatly reduced.

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In an exemplary embodiment, the radio uses a separate radar detection circuit which is made from a commercial WiFi chip and which has its own antenna. The radar detection circuit inside the WiFi chip is used for the radar detection. It may or may not share a common RF signal path with the main operating antennas. There is a benefit in radar detectability if the radar detector antenna field is less directional than that of the actual signal antennas. In one extreme example, the radar detector antenna is omnidirectional or omnidirectional in azimuth, and the transmit signal antenna is a moderate or high gain antenna. The gain difference creates a bias for detection of radar signals versus interference from the transmit signal for radar angles that are behind or on the side of the radar mainlobe.

In an exemplary embodiment with a different band used for each transmit direction in a point-to-point or multi-point-to-point link, and which requires radar detection on each band or sub-band, the radar detection performs both initial CAC and in-service monitoring, but in different ways and at different times. Upon initial bootstrapping of the link, the CAC for each radio is performed at its local transmit frequency so the local transmitter can be informed of the result, since there is no link in the other direction yet. Then, after the radios establish a connection and are operating at high duty factor, the radar detector in each transceiver switches listening frequency and in-service monitoring is performed at the local receive frequency to listen for radars and so perform in-service monitoring for the transmitter sending from the other radio. More specifically, the in-service monitoring for the downlink transmitter happens at the downlink receiver in point-to-point or at the downlink receivers in multi-point-to-point, and the in-service monitoring for the uplink transmitter (or transmitters) happens at the uplink receiver. This is to satisfy the requirement for near 100% duty factor transmission while detecting at a level that is much lower than the transmit level. The results of the in-service monitoring are communicated along the opposite link direction to the transmit side which the monitoring was being performed for (i.e. the downlink communicates the uplink radar detection information and the uplink communicates the downlink radar detection information). If, for example, the uplink radar detector senses a radar signal, it notifies the uplink transmitter through the downlink radio set. In an exemplary embodiment, a controller, such as a radio resource controller, within the transceiver having the uplink transmitter can use this exemplary radar detection result along with other link quality inputs such as estimates of other uncoordinated interference levels observed over frequency, time, space or cancellation capability as described in U.S. Provisional Patent Application Ser. No. 61/910,194, the entirety of which is incorporated herein by reference, to optimally adjust parameters such as the uplink transmit channel center frequency, transmit channel bandwidth and/or transmit power.

The invention may be best understood in the context of a design example. It will be appreciated that other designs can be used, and the exemplary design example is not meant to be limiting in any way.

The exemplary radio link includes two full duplex transceivers, typically mounted on poles and separated by a large distance, such as five hundred meters. It will be appreciated that the distance may be less than or more than five hundred meters. One transmission direction operates in the upper part of the allocated RF band, called the upper band or sub-band, and other in the lower part of the allocated RF band, called the lower band or sub-band. The point-to-point or multi-point-to-point link in the example uses one radio designated as the downlink transmitter (using the lower part of the band) and

the other as the uplink transmitter (using the upper part of the band). Each radio transceiver has a separate radar detection sensor co-located with it.

Even though the exemplary FDD operation divides this frequency band into a lower and upper band or sub-band, other implementations also can work, including, for example, overlapping bands or sub-bands, also known as Zero Division Duplexing (or ZDD) such as described in U.S. application Ser. No. 13/609,156 (now U.S. Pat. No. 8,422,540), the entirety of which is incorporated herein by reference. Within each band or sub-band the exemplary radios negotiate an operating frequency in each direction, one direction per band or sub-band. The exemplary radios use multiple transmit and receive antennas (MIMO) in each direction, and split the available transmit power among the transmit antennas or can operate with MISO, SISO, or SIMO operation. In such FDD or ZDD wireless communication systems, the transmitters in either of the uplink or downlink directions of point-to-point or multi-point-to-point systems transmit for some or all of each frame coincident in time meaning that both an uplink transmitter and a downlink transmitter are both transmitting at the same time possibly within different bands or sub-bands, possibly within the same band or sub-band or possibly even within the same channel. The remainder of this discussion will refer to these exemplary embodiment radios for purpose of explanation only, recognizing that there are many wireless communication system embodiments that can benefit from the invention.

The radio, based on an exemplary controller implemented with software and/or hardware, determines the operating frequency, within the constraints of satisfying any uniform channel usage requirement, performs medium access control using energy detection, and performs the Channel Availability Check (CAC). The CAC is a pre-scan of the channel to detect the presence of radars prior to allowing the equipment to transmit. The radio then monitors its channels using in-service monitoring.

In an exemplary embodiment, there is a brief period of time after the radar detector in the radio housing containing the downlink radio unit performs the CAC where it remains on the transmitter channel for in-service monitoring, while the transmitter channel operates at low duty factor to facilitate the detection synchronization and acquisition of the transmit signal by the other radio(s), and communicating to the other radio(s) what channel it would like to operate on. This is a bootstrap mode of operation. Once the communication link is established, the radar detector frequency channel is switched as described above so that it is listening on the receive channel to perform in-service monitoring for the transmitter in the other radio.

In a radar detection listening process, the radar detector attempts to receive signals transmitted from radars. In some embodiments, a radar detection message, control frame or status is transmitted by the radar detector if a signal received at the radar detector sufficiently matches one of a set of designated radar waveforms.

In some embodiments, the effective interference bandwidth of the radar receiver is determined. The effective interference bandwidth may be different than the occupied bandwidth of the radar transmit signal by some margin. In that case, only the effective interference bandwidth is vacated—instead of vacating a larger percentage of the overall frequency band for the required period of time (typically, 30 minutes). It will be appreciated that the period of time need not be limited to the minimum required by regulations. In some embodiments, the transceivers may remain off the channel for an extended period of time. The communication from

the radar detector to the transmitter carries information related to the bandwidth that must be vacated.

In an exemplary embodiment, the effective interference bandwidth is determined by measuring the characteristics of the pulses that comprise the radar waveform to estimate what the radar receiver signal bandwidth is. A function is applied to the measured characteristics that adjusts for the ratio of radar receiver interference bandwidth at an anticipated excess interference power to radar receiver signal bandwidth required to process the radar pulse. The radar receiver interference bandwidth that is calculated is the bandwidth that needs to be vacated around the radar center frequency. In an exemplary embodiment, the function is a simple scaling by a constant. In some embodiments, the function depends on the type of radar signal that is detected and/or the excess power level of the detected radar signal over a minimum radar detection threshold. In an exemplary embodiment, the radar signal bandwidth is the inverse of the radar pulse period measured between the half-way points of the rising and falling edge. These are exemplary embodiments and other embodiments can use other methods for estimating the radar receiver bandwidth and applying various functions to the result are also anticipated.

In an exemplary embodiment, radar detection is performed on an alternate channel on a continued basis such that if a radar detection occurs on the operating channel, the alternate channel is available for more immediate occupancy because all or part of the CAC period is already accomplished. In another exemplary embodiment, after a sufficient CAC period has passed for the alternate channel to be useable, it is continually monitored for radars in order to keep the CAC information fresh. This alternate channel may be near the occupied channel and may encounter a similar, albeit reduced, level of interference from the transmitter. Therefore, in a high duty factor transmission radio link, the alternate channel monitoring can be done, at least for small channel separation, at a remote location so the transmission signal is attenuated. The communication between the alternate channel radar detection and the transmitter is kept fresh such that at least the regulatory impact for timeliness of the information is maintained. In an exemplary embodiment, a point-to-point radio link places both the in-channel radar detector and the alternate-channel radar detector in the receiver or remote detector that can communicate back to the transmitter. In another exemplary embodiment, a point-to-multipoint (or multi-point-to-point) radio link uses the radar detector in one receiver for in-channel detection and the radar detector in another receiver for alternate channel detection.

In an exemplary embodiment, one or more radar detectors that can operate while a high-duty-factor transmitter is transmitting perform time multiplexing between radar detection on the operating channel and radar detection on an alternate channel. In a further exemplary embodiment, the CAC operation is performed while listening for a partial duty factor for a total CAC time longer than the full duty factor CAC time, and at for least a period of time related to the partial duty factor fraction. In an exemplary embodiment, the length of the partial duty factor check time is at least the CAC time divided by the fractional duty factor. In an exemplary embodiment, a point-to-multipoint radio link uses the radar detector in one receiver for in-channel detection and the radar detector in another receiver for alternate channel detection and time-multiplexes one or both for additional alternate channel coverage to provide multiple alternate channel options.

FIG. 3 shows a schematic representation of a one way radio link according to some embodiments of the invention. In FIG. 3, the radio link includes a transmitter 301 with a directional

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antenna **302**, a receiver **303** with a directional antenna **304**, and a radar detector **306** with an omnidirectional antenna **305**. In one embodiment, one or both of the transmitter **301** and receiver **303** are within an IBR transceiver as shown in FIG. 2. A communication link **307** between the radar detector **306** and the transmitter **301** is used to communicate the results of any radar detection or non-detection from the radar detector **306** to the transmitter **301**.

One problem with existing networks is that when the transmitter is transmitting, the high signal level swamps out the receive signals for typical receivers that are located in close proximity to the transmitter, thereby limiting the ability for a radar detector co-located with the transmitter to detect a radar signal. A co-located radar detector is one that is in close enough proximity to the transmitter that when antenna configurations are accounted for, the radar detector cannot detect a radar signal at the required level, as typically set by the appropriate regulatory authority, while the transmitter is transmitting. A radar detector is transmit-impaired if the signal from the transmitter prevents the radar detector from detecting radar signals at or above the regulatory limit while the impairing transmitter is emitting its transmit signal. A radar detector is not transmit-impaired if it can still detect radar signals at or above the regulatory limit while the transmitter is emitting its transmit signal. The transmitter may emit its transmit signal in the same channel as the radar detector to impair the radar detection, or the transmit signal may be emitted in a nearby channel, even if such nearby channel is in a different frequency band, and still impair the radar. The impairment can be prevented by separating the radar detector in distance from the transmitter, or by using a directional transmit antenna or directional radar-detector-receive antennas to reduce the impinging signal on the radar detector, or any other means to reduce the transmit signal level, including a cancellation circuit for cancelling the transmit signal at the input of or within the radar detector using, for example, techniques described in U.S. application Ser. No. 13/609,156 (now U.S. Pat. No. 8,422,540), the entirety of which is incorporated herein by reference.

In FIG. 3, a radar **308** with a directional antenna **309** is also shown. The radar **308** is shown relative to the range scales **310-312**. The range scales include a maximum interference range to the radar **310**, which is a range showing the maximum distance from the transmitter **301** to avoid interference with the radar **308**. The range scales also include a Max Radio Range **311** which is the maximum distance from the transmitter **301** to the receiver **303**. The range scales also include a Max Detector Range to Radar **312**, which is the maximum distance that the detector **306** can detect radar. The radar detector **306** detects radar from the radar **308** in a range that is longer than the range at which the radio transmitter **301** interferes with the radar **308**.

In operation, when the transmitter **301** operates at a high duty factor at the Max Radio Range **311**, the radar detector **306** can detect the radar **308** at a range less than the Max Detector Range to the Radar **312**. The Max Detector Range to the Radar **312** is the range at which the transmitter **301** would not interfere with the radar **308** receiver operation over the Max Interference Range to Radar **310**.

FIG. 4 shows a schematic representation of a radio link in accordance with some embodiments of the invention. In FIG. 4, the radio link includes a first transceiver **401** having an antenna **402** and a second transceiver **403** having an antenna **404**. The second transceiver **403** includes a radar sensor/detector **406**. The radar detector **406** is co-located with the transmitter of the second transceiver **403**.

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In the embodiment of FIG. 4, the radar detector **406** communicates back to the transmitter **401** using the radio transmission link between the first transceiver **401** and the second transceiver **403**. In particular, in FIG. 4, the radar results are communicated over the operational channel in the transmitter in transceiver **403** to the receiver in transceiver **401**. The radar detector **406** is shown as located in the same unit as transmitter/receiver **403** and controls the communication link **407**.

It will be appreciated that a full duplex radio link with radar detection occurring on each side (the transmit side and the receive side), may be constructed from two or more links of this nature.

FIG. 5 is a schematic representation of a radio link according to other embodiments of the invention. In FIG. 5, a radar detector **506a**, **506b** is provided in each transceiver **501**, **503**. The arrangement of FIG. 5 allows the use of the radar detectors **506** to operate as an in-service monitor on each link **507a**, **507b** and perform CAC and bootstrap in-service monitoring for its own link **507a**, **507b**.

In FIG. 5, first transceiver **501** includes a first radar detector **506a**, and the second transceiver **503** includes a second radar detector **506b**. A first communication link **507a** is provided between the transmitter of the first transceiver **501** and the receiver of the second transceiver **503**, and a second communication link **507b** is provided between the transmitter of the second transceiver **503** and the receiver of the first transceiver **501**. The communications links **507a** and **507b** are the transmission channels between the transceivers **501**, **503**.

In operation, the radar detector **506a** communicates the results of its radar detection operations to the transceiver **503** using communications link **507a**, and the radar detector **506b** communicates the results of its radar detection to the transceiver **501** using the communications link **507b**. The radar detection status results may be communicated on the transmission channel, for example, in the main data stream, the control block, or any method of signaling the information.

FIGS. 6A and 6B are time lines showing the radar detection operations for an exemplary link according to embodiments of the invention. In FIG. 6A, the timing operations of the transmitter are shown, and, in FIG. 6B, radar detection timing of a co-located radar detector is shown.

At a high-level, as shown in FIG. 6A, a CAC period **616** is followed by the low duty factor transmit periods for bootstrap, the low duty factor transmit periods for bootstrap **614** are followed by a time break **615**, and the full duty factor transmission **616** follows the time break **615**. The operations will now be described in further detail. As shown in FIG. 6A, the first event is the CAC period **613**, which is performed by the radar detector on the radio's transmit channel. Once the CAC period **613** finishes, the links lock up. Until there is a reverse communication link, there is no information that can be communicated between them. So until that point in time, any CAC **613** or in-service monitoring **614** is performed locally because there would be no way to relay that information from the other side if it were performed remotely. To accomplish the local in-service monitoring the radar detector listens at the transmit frequency. Therefore, the transmitter cannot transmit all the time or the radar detection receiver is swamped. The transmitter is operated at a low duty factor during this bootstrap period to facilitate the radar detection during this period. Once the round trip connection is made, the radar detector is switched to the receive frequency and used as a remote radar detector for the opposite side. The reverse of this happens on the other side, so that radar detection is performed at the respective receivers of both devices. FIG. 6A shows the operation of the transmitter where the high level of the pulses **14** and **16** indicate the on-time of the

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transmission. The break in timing shown by the double lines **15** indicates there is no specific time duration of these steps because that depends on the implementation.

As shown in FIG. **6B**, during the CAC period **613**, the radar detector listens for radars. During the off cycles of the low duty factor transmission, the radar detector listens on the transmit channel for radars. When the transmitter operates at full duty factor, it is no longer listening on the same channel and switches to the receive channel for the transceiver it is co-located with. The high level of the pulses **617**, **618** and **616b**, indicate the active listening time of the radar detector that is co-located in the same radio as the transmitter shown in FIG. **6A**. During the CAC period **613**, the transmitter is off, and the radar detector is listening for radars **617** on the transmitter channel. After the CAC period **613** passes, the transmitter begins transmitting at a low duty factor **614** while the radar detector still listens on the transmitter frequency channel during the off period of the transmitter duty cycle **618**. After there is a round trip connection, the transmitter operates at a high duty factor **616**, which can be as high as 100%, and the radar detector operates at a high duty factor but at the channel of the receiver in the radio housing.

FIG. **7** shows a one-sided radar detection setup which has a transmitter and receiver on one side, and a transmitter, receiver and radar detector on the other side. The radar detector relays its results through the communication means through its local transmitter to the receiver on the other side, as a notification that the transmitter on the other side must stop transmitting. The exemplary block diagram in FIG. **7** indicates an exemplary implementation corresponding to the embodiment shown in FIG. **4**.

FIG. **7** shows a radio link between a first transceiver **720** and a second transceiver **721**. The second transceiver **721** includes a Band B receiver **722** and a Band A transmitter **723** in communication with one another over communications link **724**. The Band A transmitter includes **723** includes a directional antenna **725**, and the Band B receiver includes a directional antenna **726**. The first transceiver **720** includes a Band A receiver **732** having a directional antenna **727** and a Band B transmitter **731** having a directional antenna **728**. The first transceiver **720** further includes a Bands A and B Radar detector **730** having an omni-directional antenna **735**. The Bands A and B Radar detector **730** is in communication with the Band B transmitter over link **729**. The normal payload transmission traffic between transceivers **720** and **721** occurs over communications link **734** in the reverse direction on Band A and is transmitted by the Band A transmitter **723** and received by the Band A receiver **732**.

In FIG. **7**, the interaction between the Bands A and B radar detector **730** and the transmitter **723** is shown as a communication to the local transmitter **729** and the communication **733** through the local transmitter **729** to the remote receiver **726** is the combination of the radar information and the radio payload on transmission Band B. In this case, the Bands A and B radar detector **730** first listens through the omnidirectional antenna **735** on Band B for the CAC and low duty factor transmission from the Band B transmitter **731** through the directional antenna **728**. The Bands A and B radar detector **730** signals through communication link **729** if the channel is clear or blocked. After bootstrap, the Bands A and B radar detector **730** switches its listening frequency to Band A and performs in-service monitoring for Band A transmitter **723**. If the Bands A and B radar detector **730** detects a radar, it signals through communication link **729** to the Band B transmitter **731**, and then over the air on radar detection results Communication and Payload Transmission **733** to radio **721**. The radar detection results are received by the Band B receiver

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722 through antenna **726**. The Band B receiver **722** sends control information over link **724** to indicate to the Band A transmitter **723** that transmission needs to stop. The radio **721** then selects an alternate operating frequency if one is available.

FIG. **8** shows a two-way link which has a transceiver and radar detector on both sides of the link. The radar detector on each side of the link uses its local communication links to either enable/disable its local transmitter after CAC and during bootstrap, or to communicate to the other side of the link to indicate to the other side that the transmitter has a clear channel or must stop transmitting due to a radar on its channel.

In particular, as shown in FIG. **8**, the two-way link includes a first transceiver **820** and a second transceiver **821**. The second transceiver **821** includes a Band B receiver **822** and a Band A transmitter **823** in communication with one another over communications link **824**. The Band A transmitter includes **823** includes a directional antenna **825**, and the Band B receiver includes a directional antenna **826**. The second transceiver **821** further includes a Bands A and B Radar Detector **837** and an omni-directional antenna **838**. A communications link **835** is provided between the Bands A and B Radar detector **837** and the Band A transmitter **823**. The first transceiver **820** includes a Band A receiver **832** having a directional antenna **827** and a Band B transmitter **831** having a directional antenna **828**. A communications link **829** is provided between the Band A receiver **832** and the Band B transmitter **831**. The first transceiver **820** further includes a Bands A and B Radar detector **830** and an omni-directional antenna **839**. The Bands A and B Radar detector **830** is in communication with the Band B transmitter over link **836**. The normal payload transmission traffic between transceivers **820** and **821** occurs over link **834** in the reverse direction on Band A and is transmitted by the Band A transmitter **823** and received by the Band A receiver **832**.

An exemplary sequence can be that each side listens in its respective transmit band, Band A for radio **821b** and Band B for radio **820**, during the respective CAC periods **17**. After each radio passes CAC, the transmitter on one side, for example Band A transmitter **823**, starts transmitting at low duty factor, and the Band A and B radar detector **837** performs in-service monitoring. After the Band A receiver **832** locks to the Band A transmitter **823**, there is a reverse link transmission that locks the Band B transmitter **831** to the Band B receiver **822**. Then, the Band A and B radar detectors **837** and **830** switch from their respective transmit bands to their respective receive bands, the Bands A and B Radar Detector **830** listens on Band A to monitor for radars in the channel of the Band A transmitter **823** and the Bands A and B Radar Detector **837** listens on Band B to monitor for radars in the channel of the Band B transmitter **831**.

FIG. **9** shows that the same approach is scalable to a point-to-multipoint network. It will be appreciated that the approach is also scalable to multiple point-to-point, ad hoc, ring, self-organizing, relay, mesh and other network architectures. It will be appreciated that the approach may be used with any connectivity architecture.

In FIG. **9**, a third transceiver **939** is part of the network (or system). The third transceiver **939** is shown in FIG. **9** directly connected to transceiver **921**. It will be appreciated that the third transceiver **939** could alternatively be directly connected to transceiver **920**. In one exemplary embodiment, the transceiver **921** is a multipoint aggregator and transceivers **920** and **939** are multipoint remote units. In this case, each of the remote transceivers **920**, **939** performs its own CAC on its respective transmit bands. After locking to the multipoint

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aggregator **921**, the transceivers **920, 939** switch their Band A and B radar detectors to their receive bands to do in-service monitoring in the Band A Transmitter transmit band. If a radar is detected in one of the remote radios **920, 939**, the aggregation radio **921** is informed through the communications link and it stops transmitting on that channel. A new channel is determined for both remote transceivers **920, 939**. It will be appreciated that the results of individual radar detectors may be communicated to the other radios (not shown) in a sub-net or area wide network.

In the point-to-multipoint configuration of FIG. 9, the radar detection task is distributed among the remote transceivers **920, 939** such that they perform detection on different parts of the radar detection band or the useable bandwidth, each detecting on a portion of the bandwidth of interest, and including but not limited to one detecting on the operating channel while the other detects on an alternate channel that can be used as a hot spare to jump to in the event the operating channel must be vacated. The radar detectors in the radio system become a shared resource or network of radar detectors tied together through a communications systems, where the detectors are used cooperatively, or in a coordinated manor, to perform in-service monitoring, channel look ahead, extended detection bandwidth, and more reliable detectability through location, angle, and antenna diversity. In an exemplary embodiment, one remote radio detects on part of the channel bandwidth and the other remote radio detects on the remaining part. With more radar detectors, the load can be divided appropriately. In another exemplary embodiment, one remote radio performs radar detection on an assigned portion of the band or sub-band where the operating channel is, and at least one other radar detector in a different location performs radar detection in another portion of the band or sub-band, which is then available immediately if the operating channel has to be vacated. In one exemplary embodiment the distribution of detection bandwidth, operating bands, or sub-bands is determined early in the bootstrap period, and, in another exemplary embodiment, it is dynamically determined once the radio locks up and enters in-service monitoring. These radar detectors communicate their results back to the multipoint aggregator **921**, or to each other in other configurations of the intercommunication. In a further exemplary embodiment, the aggregator **921** also has a radar detector co-located with the transmitter that can operate in the band or sub-band but sufficiently spaced from the operating channel that it is protected from the transmission and can perform radar detection on these well-separated channels to provide alternate channel availability for the transmitter.

One or more of the methodologies or functions described herein may be embodied in a computer-readable medium on which is stored one or more sets of instructions (e.g., software). The software may reside, completely or at least partially, within memory and/or within a processor during execution thereof. The software may further be transmitted or received over a network.

The term "computer-readable medium" should be taken to include a single medium or multiple media that store the one or more sets of instructions. The term "computer-readable medium" shall also be taken to include any medium that is capable of storing, encoding or carrying a set of instructions for execution by a machine and that cause a machine to perform any one or more of the methodologies of the present invention. The term "computer-readable medium" shall accordingly be taken to include, but not be limited to, solid-state memories, and optical and magnetic media.

Embodiments of the invention have been described through functional modules at times, which are defined by

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executable instructions recorded on computer readable media which cause a computer, microprocessors or chipsets to perform method steps when executed. The modules have been segregated by function for the sake of clarity. However, it should be understood that the modules need not correspond to discreet blocks of code and the described functions can be carried out by the execution of various code portions stored on various media and executed at various times.

It should be understood that processes and techniques described herein are not inherently related to any particular apparatus and may be implemented by any suitable combination of components. Further, various types of general purpose devices may be used in accordance with the teachings described herein. It may also prove advantageous to construct specialized apparatus to perform the method steps described herein. The invention has been described in relation to particular examples, which are intended in all respects to be illustrative rather than restrictive. Those skilled in the art will appreciate that many different combinations of hardware, software, and firmware will be suitable for practicing the present invention. Various aspects and/or components of the described embodiments may be used singly or in any combination. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the claims.

What is claimed is:

1. A wireless communications system comprising:

a first transceiver, wherein the first transceiver comprises a first transmitter and a first receiver, and wherein the first transmitter transmits on a first transmit channel;

a second transceiver, wherein the second transceiver comprises a second transmitter and a second receiver, and wherein the second transmitter transmits on a second transmit channel;

wherein the first receiver receives from the second transmitter on the second transmit channel and the second receiver receives from the first transmitter on the first transmit channel;

wherein the first transmit channel is within a first transmit frequency band and the second transmit channel is within a second transmit frequency band;

a first radar detector, wherein the first radar detector is configured to detect radar signals within a first radar detection frequency range that includes at least part of the second transmit frequency band;

wherein the first radar detector is configured to detect radar signals within at least a first time period, the first time period comprising at least a first period of time when the first transmitter and the second transmitter both transmit coincident in time;

wherein the first radar detector communicates at least a first radar detection result to the second receiver;

wherein the first radar detection result is an input to a first controller associated with the second transmitter; and

wherein the first controller controls a transmission from the second transmitter based on the first radar detection result; and

wherein the first radar detector is configured to be not transmit-impaired by the second transmitter when the second transmitter transmits, at least in part due to a physical separation of the first radar detector and the second transmitter.

2. The wireless communications system of claim **1** wherein the first radar detector is configured to be not transmit-impaired by the first transmitter when the first transmitter transmits, at least in part due to a physical separation of the first radar detector and the first transmitter.

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3. The wireless communications system of claim 1 wherein the first radar detector is configured to be not transmit-impaired by the first transmitter when the first transmitter transmits, at least in part due to an antenna pattern of the first radar detector relative to the antenna pattern of the first transmitter.

4. The wireless communications system of claim 1 wherein the first controller associated with the second transmitter is capable of causing an adjustment of at least one adjustable parameter associated with the transmission of the second transmitter.

5. The wireless communications system of claim 4 wherein the at least one adjustable parameter associated with the transmission of the second transmitter is a transmit power.

6. The wireless communications system of claim 4 wherein the at least one adjustable parameter associated with the transmission of the second transmitter is a center frequency.

7. The wireless communications system of claim 5 wherein the transmit power of the second transmitter after the adjustment is at a level below that of a regulatory limit for transmit power within a channel for which a radar signal has been detected.

8. The wireless communications system of claim 1 wherein the first radar detection frequency range includes at least 80% of a bandwidth of the second transmit channel.

9. The wireless communications system of claim 8 wherein the first radar detection frequency range further includes at least 80% of a bandwidth of a first alternate channel that is different from the second transmit channel.

10. The wireless communications system of claim 1 wherein the first radar detection result is communicated within a radar detection message, control frame or status that at least indicates whether or not at least one radar signal has been detected within the first radar detection frequency range.

11. The wireless communications system of claim 1 wherein the first radar detection result is communicated within a radar detection message, control frame or status that at least indicates whether or not at least one radar signal has been detected within the second transmit channel.

12. The wireless communications system of claim 10 wherein the radar detection message, control frame or status indicates a bandwidth of the at least one detected radar signal within the first radar detection frequency range.

13. The wireless communications system of claim 1 wherein the part of the first time period when at least the first transmitter and the second transmitter both transmit coincident in time is 100% of the first time period for which the first radar detector is configured to at least detect radars.

14. The wireless communications system of claim 4 wherein the first controller associated with the second transmitter is capable of causing the adjustment based at least upon the first radar detection result.

15. The wireless communications system of claim 1 wherein the first transmit frequency band overlaps in frequency with the second transmit frequency band.

16. The wireless communications system of claim 1 wherein the first radar detection frequency range does not overlap in frequency with the first transmit frequency band.

17. The wireless communications system of claim 1 wherein the first radar detection frequency range is identical to or a subset of the second transmit frequency band.

18. The wireless communications system of claim 1 further comprising: a second radar detector;

wherein the second radar detector is configured to detect radar signals within at least a second time period, the second time period comprising at least a period of time when the first transmitter and the second transmitter both transmit coincident in time; and

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wherein the second radar detector is configured to detect radar signals within a second radar detection frequency range.

19. The wireless communications system of claim 18 wherein the first time period overlaps in time with the second time period.

20. The wireless communications system of claim 18 wherein the second radar detection frequency range excludes the second transmit channel.

21. The wireless communications system of claim 18 wherein the second radar detection frequency range includes at least a second alternate channel that is different from the second transmit channel.

22. The wireless communications system of claim 18: wherein the second radar detector communicates at least a second radar detection result to the second receiver; and wherein the second radar detection result is an input to the first controller associated with the second transmitter.

23. The wireless communications system of claim 22 wherein the second radar detection result is communicated within a radar detection message, control frame or status that at least indicates whether or not at least one radar has been detected within the second alternate channel.

24. The wireless communications system of claim 18: wherein the second radar detector communicates at least a second radar detection result to the first receiver; wherein the second radar detection result is an input to a second controller associated with the first transmitter; and wherein the second controller controls a transmission from the first transmitter based on the second radar detection result.

25. The wireless communications system of claim 18 wherein the second radar detection frequency range is identical to or a subset of the first transmit frequency band.

26. The wireless communications system of claim 23 further comprising:

a third radar detector;

wherein the third radar detector is configured to detect radar signals within at least a third time period, the third time period comprising at least a period of time when the first transmitter and the second transmitter both transmit coincident in time;

wherein the third radar detector is configured to detect radar signals within a third radar detection frequency range;

wherein the third radar detector communicates at least a third radar detection result to the first receiver; and wherein the third radar detection result is an input to a third controller associated with the first transmitter.

27. The wireless communications system of claim 1 further comprising:

a first cancellation circuit, wherein the first cancellation circuit is coupled to at least the first radar detector;

and wherein the first cancellation circuit generates a first cancellation signal representative of an output of the first transmitter such that the first cancellation signal in combination with a received signal for the first radar detector together result in a reduced level of first transmitter signal impairment within the first radar detector.

28. The wireless communications system of claim 1 further comprising:

a second radio resource controller, wherein the second radio resource controller comprises the first controller associated with the second transmitter;

and wherein the second radio resource controller is capable of causing an adjustment of at least one adjustable

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parameter associated with the transmission of the second transmitter based upon at least one additional link quality input and the first radar detection result.

29. The wireless communications system of claim 24 further comprising:

a first radio resource controller, wherein the first radio resource controller comprises the second controller associated with the first transmitter;

and wherein the first radio resource controller is capable of causing an adjustment of at least one adjustable parameter associated with the transmission of the first transmitter based upon at least one additional link quality input and the second radar detection result.

30. The wireless communications system of claim 1 wherein the first radar detector is configured to be not transmit-impaired by the second transmitter when the second transmitter transmits, at least in part due to an antenna pattern of the first radar detector relative to the antenna pattern of the second transmitter.

31. The wireless communications system of claim 4 wherein the at least one adjustable parameter associated with the transmission of the second transmitter is a channel bandwidth.

32. The wireless communications system of claim 10 wherein the radar detection message, control frame or status indicates a transmission frequency of the at least one detected radar signal within the first radar detection frequency range.

33. The wireless communications system of claim 1 wherein the first transceiver further comprises the first radar detector.

34. The wireless communications system of claim 22 wherein the first transceiver further comprises the second radar detector.

35. The wireless communications system of claim 26 wherein the second transceiver further comprises the third radar detector.

36. The wireless communications system of claim 26 wherein the third controller is comprised within the second controller.

37. The wireless communications system of claim 27 wherein the first transceiver further comprises the first cancellation circuit.

38. The wireless communications system of claim 1 further comprising:

a second cancellation circuit, wherein the second cancellation circuit is coupled to at least the first radar detector; and wherein the second cancellation circuit generates a second cancellation signal representative of an output of the second transmitter such that the second cancellation signal in combination with a received signal for the first radar detector together result in a reduced level of second transmitter signal impairment within the first radar detector.

39. The wireless communications system of claim 29 wherein the first transceiver further comprises the first radio resource controller.

40. The wireless communications system of claim 28 wherein the second transceiver further comprises the second radio resource controller.

41. The wireless communications system of claim 1 wherein the first transmit frequency band is coincident with the second transmit frequency band.

42. The wireless communications system of claim 1 wherein the first radar detection frequency range is coincident with the second transmit channel.

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43. The wireless communications system of claim 4 wherein the at least one adjustable parameter associated with the transmission of the second transmitter is a time of transmission.

44. The wireless communications system of claim 20 wherein the second transceiver further comprises the second radar detector.

45. The wireless communications system of claim 1 wherein the first radar detector communicates at least the first radar detection result to the second receiver via the first transmitter.

46. The wireless communications system of claim 22 wherein the second radar detector communicates at least the second radar detection result to the second receiver via the first transmitter.

47. The wireless communications system of claim 26 wherein the third radar detector communicates at least the third radar detection result to the first receiver via the second transmitter.

48. The wireless communications system of claim 27 further comprising:

a second cancellation circuit, wherein the second cancellation circuit is coupled to at least the first radar detector; and wherein the second cancellation circuit generates a second cancellation signal representative of an output of the second transmitter such that the second cancellation signal in combination with a received signal for the first radar detector together result in a reduced level of second transmitter signal impairment within the first radar detector.

49. The wireless communication system of claim 48 where the second cancellation circuit is comprised within the first cancellation circuit.

50. A wireless communications system comprising:

a first transceiver, wherein the first transceiver comprises a first transmitter and a first receiver, and wherein the first transmitter transmits on a first transmit channel;

a second transceiver, wherein the second transceiver comprises a second transmitter and a second receiver, and wherein the second transmitter transmits on a second transmit channel;

wherein the first receiver receives from the second transmitter on the second transmit channel and the second receiver receives from the first transmitter on the first transmit channel;

wherein the first transmit channel is within a first transmit frequency band and the second transmit channel is within a second transmit frequency band;

a first radar detector, wherein the first radar detector is configured to detect radar signals within a first radar detection frequency range that includes at least part of the second transmit frequency band;

wherein the first radar detector is configured to detect radar signals within at least a first time period, the first time period comprising at least a first period of time when the first transmitter and the second transmitter both transmit coincident in time;

wherein the first radar detector communicates at least a first radar detection result to the second receiver;

wherein the first radar detection result is an input to a first controller associated with the second transmitter; and wherein the first controller controls a transmission from the second transmitter based on the first radar detection result; and

wherein the first radar detector is configured to be not transmit-impaired by the second transmitter when the

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second transmitter transmits, at least in part due to a physical separation of the first radar detector and the second transmitter; and

wherein the first radar detector is configured to be not transmit-impaired by the first transmitter when the first transmitter transmits, at least in part due to a physical separation of the first radar detector and the first transmitter.

51. A wireless communications system comprising:

- a first transceiver, wherein the first transceiver comprises a first transmitter and a first receiver, and wherein the first transmitter transmits on a first transmit channel;
- a second transceiver, wherein the second transceiver comprises a second transmitter and a second receiver, and wherein the second transmitter transmits on a second transmit channel;

wherein the first receiver receives from the second transmitter on the second transmit channel and the second receiver receives from the first transmitter on the first transmit channel;

wherein the first transmit channel is within a first transmit frequency band and the second transmit channel is within a second transmit frequency band;

a first radar detector, wherein the first radar detector is configured to detect radar signals within a first radar

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detection frequency range that includes at least part of the second transmit frequency band;

wherein the first radar detector is configured to detect radar signals within at least a first time period, the first time period comprising at least a first period of time when the first transmitter and the second transmitter both transmit coincident in time;

wherein the first radar detector communicates at least a first radar detection result to the second receiver;

wherein the first radar detection result is an input to a first controller associated with the second transmitter; and

wherein the first controller controls a transmission from the second transmitter based on the first radar detection result; and

wherein the first radar detector is configured to be not transmit-impaired by the second transmitter when the second transmitter transmits, at least in part due to a physical separation of the first radar detector and the second transmitter; and

wherein the first radar detector is configured to be not transmit-impaired by the first transmitter when the first transmitter transmits, at least in part due to an antenna pattern of the first radar detector relative to the antenna pattern of the first transmitter.

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